TOWARD A SYSTEM FOR DESIGN COLLABORATION THAT SUPPORTS INTERACTION AND INFORMATION SHARING

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TOWARD A SYSTEM FOR DESIGN COLLABORATION THAT SUPPORTS INTERACTION AND INFORMATION SHARING

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SUMMARY

This thesis presents two empirical studies of four pairs of design students collaborating on two small products design sessions in both face-to-face and distributed settings while using computer-mediated communication (CMC) technologies and a Collaborative Virtual Environment (CVE). To gain insight about the way designers communicate and collaborate, the observation focused on how much time the students worked "together" and "individually" in the design process. Each design process was video recorded and analyzed with a video analysis software Observer XT. The first study shows that both teams worked together to arrive at a design concept then they divided the work for each person to work independently (either the 3D modeling task or the 2D graphic task) to produce the final design. Teams worked together less than fifty percent of the overall work time because they could not share design information effectively using the computing technology tools on the collaborative design process.

Findings of the first study suggested plausible design criteria for communication tools for distributed collaboration that supports interaction and sharing design information. The second study used the same methodology and experimental procedures as those used in study. However, participants were provided a shared tool such as NetMeeting *Whiteboard* and *Shared program* that support shared sketching abilities or shared viewing of 3D objects. The study shows that teams spent more time working together when using programs that support shared sketching abilities or shared viewing of 3D objects. The shared program and the whiteboard function from NetMeeting helped the design teams to share more information. Participants commented that this program helped

facilitate the collaborative process by enabling them each to perform multiple tasks such as talking with their teammates and observing 3D object in a shared view at the same time. Participants also reported that they found the distributed setting a more engaging environment to work with teammates because they were "forced to be engaged" and "forced to communicate better," and that they "concentrated more using hand gestures on camera."

Although two studies showed that current CVE (Unreal) did not lead to effective collaboration, several potential features such as creating virtual mock-ups for the brainstorming within a virtual environment were introduced. Participants consider real time 3D visualization effective in the design process and thus very promising in the collaborative setting if they can share ideas easily within a 3D virtual environment.

CHAPTER 1

INTRODUCTION

Problem

Individuals working on design teams are increasingly geographically distributed. That is, they work in different locations. As a result, they often use email, chat, and shared graphic files to work collaboratively. Additionally, they are becoming more proficient with 2D or 3D computer-aided design (CAD) tools, increasing their ability to collaboratively share, evaluate, and critique virtually (usually by sharing the drawings over the Internet via email) (Craig & Zimring, 2000; Lawson, 2004). As the number of geographically-distributed design teams grows, a question arises as to how these designers can effectively collaborate on design processes.

Despite advancements in modern computer mediated technology for remote communication (such as email, messenger, and video conference), numerous studies have demonstrated that face-to-face is the most effective form of communication (Hiltz, Johnson, & Turoff, 1986; Lebie, Rhoades, & McGrath, 1995; Warkentin, Sayeed, & Hightower, 1997; Wilson, Straus, & McEvily, 2006). In other words, members of distributed teams exchange information less effectively than those of face-to-face teams. Therefore, there is a need for distributed collaboration tools.

Despite the increase in collaborative design practice, the majority of designers are not completely satisfied with how their companies share project information. In a recent study, 79% of questionnaire respondents stated their dissatisfaction with the CAD review (Design Development, 2009). Current CAD software for viewing and commenting on another's work is limited, so the majority of design firms typically end up sending CAD drawings to other collaborators by emails. In fact, architects and design teams get countless emails from other collaborators such as contractors, clients or mechanical engineers, as illustrators in Figure 1.1. However, firms realize that Email is inconsistent, difficult to organize so it is not intended for collaboration (Attolist, 2006-2008).

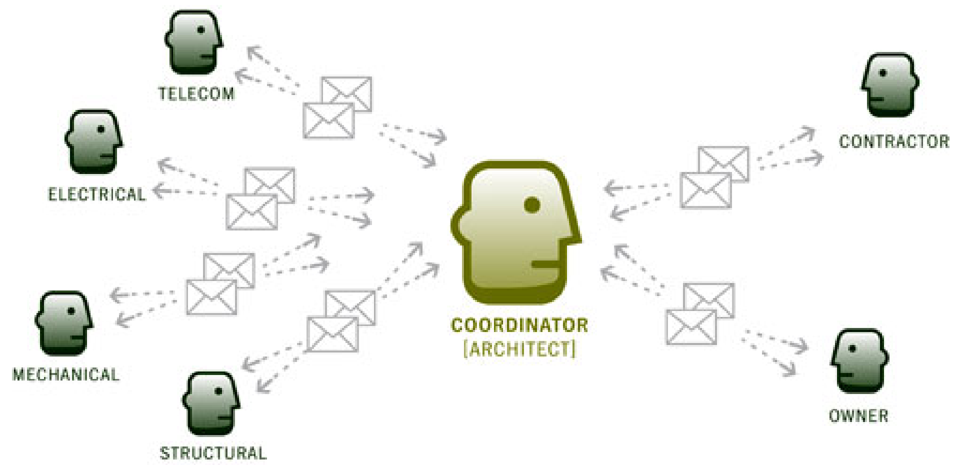


Figure 1.1 Communication with Email for Design Teams (Attolist, 2006-2008)

As problems arise, it is important to know whether existing computer-mediated communication (CMC) technologies, such as email or instant messenger, and Collaborative Virtual Environments (CVEs), such as virtual reality and CAD software, can make distributed collaborations as effective as group work in a face-to-face setting.

This research will investigate how geographically distributed design teams create and share design information using technologies, what virtual communication is lacking for design teams compared to face-to-face setting, and what type new system is needed for distributed collaboration.

Purpose of the Study

The main purpose of this research was to develop recommendations for a system that would more effectively supports design communication, interaction of designers and the sharing of design information. Therefore, this study examined design teams, focusing on general issues of collaboration in design teams and the types of technologies used in such collaboration. In particular, it focused on whether computer-mediated communication (CMC) technologies and collaborative virtual environments (CVE) could facilitate design collaboration in distributed settings, and if so, which types were most effective in promoting collaboration. Thus, the purpose of the study was to answer the following primary research questions:

- How do design teams communicate and collaborate using CMC technologies and CVE during the design process to perform collaborative team work?
- How does collaboration by distributed design teams differ from that by face-to-face teams in their use of both traditional and computer-supported tools through the design process?
- What are the important elements for a new computer-supported system for distributed collaboration that will support the interaction and the sharing of design information?

Significance of the Study

Many studies have shown that groups produce better results than any individual (Dufner, Kwon, Park, & Peng, 2002; Hill, 1982; Kerr & Tindale, 2004; Lorge, Fox, Davitz, & Brenner, 1958; Yetton & Bottger, 1982). In fact, studies of creativity by Lawson (1997) have suggested that few individuals are highly creative. The design process is something that inherently cannot be done by an individual alone (Kvan, 2000; Lawson, 1997, 2004). Therefore, the success of most design projects depend on team membership and how the members share and support each others' ideas, and collaborative activities comprise an integral part of teamwork (Lawson 1997; Kvan 2000).

Although a number of studies have examined the role of computer supported communication in distributed teams (e.g., education, training) (Craig & Zimring, 2000;

Mohan & Maher, 1989; Redfern & Naughton, 2002; Sherry & Myers, 1998), little research has focused on the role of computer-supported systems in promoting effective collaboration among designers in a distributed environment. Therefore, study for collaborative design teams is unique since design projects tend to become more and more geographically distributed (Détienne, 2006).

CHAPTER 2

BACKGROUND RESAERCH

This chapter reviews studies related to collaboration in design and types of computer-supported technologies for design teams. The study focused on how designers work and communicate in teams and the types of existing technologies that could be used for design collaboration. The understanding of the design process will inform the potential tools that the study will use for the experiment.

Collaboration in Design Teams

To propose a new system for distributed collaboration that will support interaction and design information sharing, the study needs to understand the way designers collaborate in teams. With the understanding, a decision about what might support better collaboration for design teams can be reached. Therefore, this section defines collaborative design and the activities and communication in design teams to provide a more in-depth understanding of how designer teams deal with design problems.

What is Collaborative Design

Collaboration in design is considered an activity in which more than two people work together toward a final solution (Chiu, 2002; Lawson, 1997; Saad & Maher, 1996). Designers work collaboratively when they share design objectives through visual representations such as sketches, tools, and materials (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004). In the design process, a group of designers work as a team on a shared representation of design requirements, drawings, and document (Maher, Gero, &

Saad, 1993). While design is often a collective process between two group members (Lawson 1997), the design process itself is a collective process among group members.

Despite a clear definition of collaboration, that is, people working together, collaboration in design teams is not a simple process because the design itself is a complex activity. In a design environment, simply working together and talking about the same subject might not be considered collaboration (Sudweeks & Allbritton, 1996). Kvan (2000) defines two different types of design collaboration processes: "close-coupled design" and "loosely-coupled design". A close-coupled design is a process in which designers work intensely with one another during the whole design process to produce a design as illustrated in Figure 2.1.

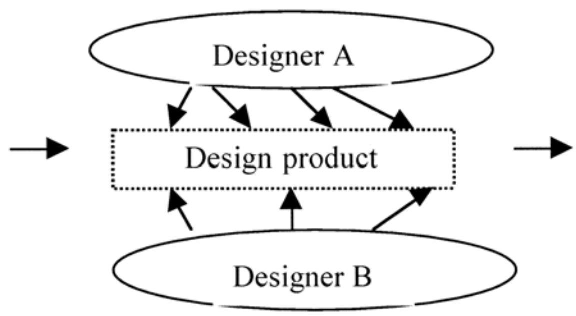


Figure 2.1 Close Coupled Design Process (Kvan, 2000)

However, a more common type of collaboration in design teams is a loosely-coupled design process, as shown in Figure 2.2, in which each experienced designer contributed different domains of expertise at times to solve a shared problem (Kvan, 2000). Kvan said process might be cooperative rather than collaborative.

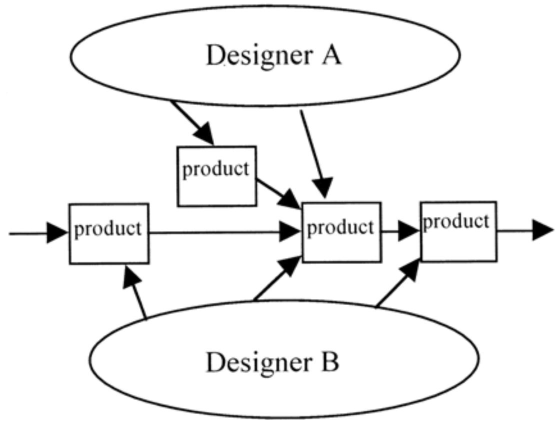


Figure 2.2 Loosely-Coupled Design Process (Kvan, 2000)

Kvan suggested that collaboration in design teams requires planning, negotiation, and then evaluation among team members, which more closely resembles a cooperative rather than a collaborative design process (Kvan, 2000). Individual work occurs after the negotiation phase of design collaboration, illustrated in Figure 2.3.

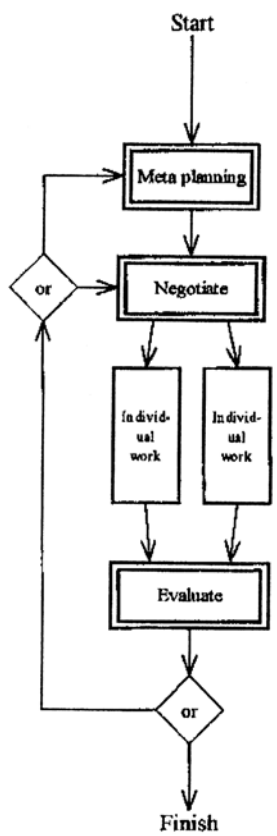


Figure 2.3 A Model of Design Collaboration (Kvan, 2000)

In other words, collaboration emerges when designers plan, negotiate, and evaluate their design (Eastman, 1969; Gross, et al., 1998; Kan, Duffy, & Su, 2001; Kvan, 2000). Whereas a single designer does not have to deal with negotiation, mutual agreement is necessary in design teams (Saad & Maher, 1996). In fact, many studies demonstrate that design depends heavily upon negotiation strategies from social interaction (Brereton, Cannon, Mabougunje, & Leifer, 1996; Cheng & Kvan, 2000; Cross, 2006)

Design Activities in Design Teams

Since any collaborative design activity must take place in space and time, researchers have identified four patterns by space and time to classify the events for design activity (Peng, 2001).

<u>Design Activities in Face-to-face and Distributed</u>

Face-to-face and distributed collaborations exhibit different patterns. Face-to-face collaboration happens when designers have a meeting or a brainstorming session for intensive communication among group members at the same geographical location via face-to-face simultaneous interactions (Peng, 2001). These interactions are mediated by the physical proximity of team members, and provide increased spontaneous conversations (Sanford, 2008). Because of the physical proximity, collocated, face-to-face interaction is the most effective form of communication (Hiltz, et al., 1986; Lebie, et al., 1995; Warkentin, et al., 1997; Wilson, et al., 2006).

Distributed collaboration occurs for teams who are geographically distributed, so they are unable to have direct face-to-face communication. Many researchers believe that social interaction via face-to-face communication can provide information of need for distributed collaboration in the shared workspace because designers are themselves skilled at coordination communication (Ishii & Arita, 1991; Ishii & Kobayashi, 1992; Ishii & Ohkubo, 1990; Tang, 1989).

Design Team Activities

Design is a complex intellectual activity (Gero & Mc Neill, 1998). Thus, one cannot know or understand the process an individual designer has followed to create a design, as such a process cannot be directly measured from the designer's brain (Stempfle & Badke-Schaub, 2002). Although counter-intuitive, the understanding of the process of a design team activity is easier because when designers work in teams, they must communicate to share their ideas (Lawson, 1997). Because of this, design activities in teams can be measured by observing and coding of their communicative activities (Ishii & Arita, 1991; Ishii & Kobayashi, 1992; Ishii & Ohkubo, 1990; Tang & Leifer, 1988).

Successful Collaborative Design

To achieve successful collaboration, information sharing is very important for teams because they receive various types of information each design phases (Lawson, 2004; Poltrock, et al., 2003). In early phases, designers generate ideas through their sketches, but in the later detailed phases, they examine and produce more intricate work (Cross, 2006; Lawson, 1997, 2004) . Researchers found that designers focus on design ideas during the sketching and on the creation of the design model in a 3D virtual world (Gero, et al., 2004; Maher, Bilda, & Gül, 2006; Maher & Simoff, 2000).

Obviously, the success of collaboration in design is evaluated by a team's performance rather than by the team members' individual work (Kvan, 2000).

Researchers propose three ways to measure the success of group effectiveness: task interdependence (how closely group members work together), outcome interdependence (whether and how group performance is rewarded), and potency (members' beliefs that the group can be effective) (Sbea & Guzzo, 1987).

Communication in Design Teams

Collaborative design involves a significant amount of communication among design teams (Maher, Cicognani, & Simoff, 1996). In design teams, designers express ideas, listen, and share ideas to negotiate when they collaborate. That is, communication includes the elaboration of their design ideas followed by a conversations with others (Maher, Simoff, & Cicognani, 2000). In teamwork, communication is necessary to share expertise, ideas, resources, or responsibilities (Cross & Cross, 1995).

Communication Modalities In Design Teams

Communication modalities are categorized by talking (verbal communication), gesturing (non-verbal communication), drawing, and modeling. The vital component of any collaborative process is that individuals share their thoughts through verbal communication. Many studies have shown that a high level of verbal communication helps a team succeed in developing concepts (Teasley, 1997). In the design team, team members identify the solution of problems by levels of commitment to producing utterances or gestures (Brereton, et al., 1996). Therefore, depending on the level of verbal communication, design teams demonstrate varying levels of success during this process.

Unlike any other collaborative process, graphic communication such as drawing modeling, and physical mock-up is required, specifically in a design team. The drawing is a significant source of knowledge that designers use (Lawson, 2004). Therefore, designers are trained to draw using pen and pencil to generate, develop new ideas , and eventually to communicate their thinking (Do, 1998). Indeed, this graphic communication is a fundamental medium to communication during the design process (Cross, 2006; Gross, et al., 1998; Lawson, 1997, 2004).

Drawing and talking also represent an important relationship in design groups. Cross (2006) conducted a study in which design groups had to design a device for carrying a hiker's backpack on a mountain bicycle. Analyzing the experiment, he pointed out the effectiveness of "words" in the design process because he could identify how designers work together while coding their speech rather than just evaluating final design outcomes. Although drawing and talking have different advantages in the design process, they are equally powerful media in collaboration (Cross, 2006).

Among the communication modalities in teams, verbal communication and graphic communication can play significant roles in the collaborative design process when two designers are exchanging ideas (Craig & Zimring, 2002).

Communication Problem in Design Teams

Communication occurs when sharing design information, making decisions, and coordinating design tasks (Chiu, 2002). Chiu (2002) proposed conditions of communication among multiple persons when they are in a distributed settings. Many communication channels such as shared ideas, shared resources, and shared representations occur when designer collaborate, illustrated in Figure 2.4, especially when they are distributed. Researchers (Chiu, 2002; Chiu, 2001) found typical communication problems in design collaboration as follows:

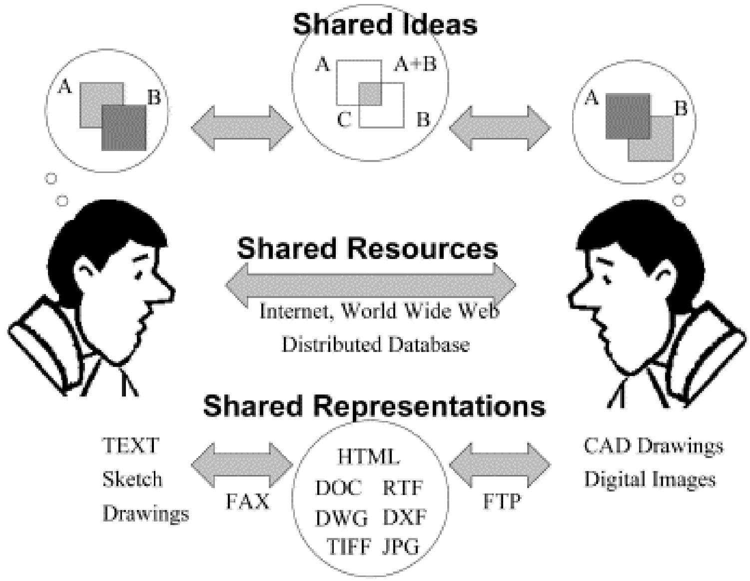


Figure 2.4 Communication Conditions Among Multiple Persons (Chiu, 2002)

- The media problem: how to transmit communication symbols
- The semantic problem: how to let transmitted symbols carry their original meaning without interference
- The performance problem: how to effectively receive meaning in messages
- The organizational problem: how to reach the right persons for sharing expertise or ideas, design information.

Significantly more problems in communication arise in distributed design teams than in face-to-face teams because the former are in different places. Because teams must use technology to communicate while they are distributed, better technology might lead to more effective communication among distributed design teams (Cheng, 2003; Lahti, et al., 2004; Stempfle & Badke-Schaub, 2002).

Computer-Supported Collaborative Design

While designers in a common physical setting discuss the design project through direct communication, design teams in a geographically distributed setting do not, which limits their communication. As the number of geographically-distributed design teams are growing, a greater need for technology has arisen, as when members are not collocated, they must use technology (Hinds, 2003). Technology enables communication and information sharing between distributed design teams (Simoff & Maher, 2000).

Distributed team design activities are strongly influenced by the use of technologies such as exchanging files and interacting on shared digital models (Cross, 2006). Computer-supported systems may enhance design communication when designers are distributed because they enable design teams to work together while in a distributed environment (Chiu, 2002; Hinds, 2003). Therefore, we need to be aware of what computer-supported tools are available, how they enhance design communication, and how they differ.

Computer-Aided Design (CAD) in Design

Computer-aided design (CAD) is a digital communication medium for visualizing and documenting a design solution (Maher, et al., 1993). Mainly used for 3D models or 2D drawings of physical components, it is also used in the processes of the conceptual design and layout of products (McKinney & Fischer, 1998). One of the advantages of this digital medium is the ability to modify design information as computer files (Maher, et al., 2000). Designers use CAD systems to visualize the design through the manipulation of 2D and 3D graphic objects before they are physically constructed or manufactured (Saad & Maher, 1996).

However, the CAD system, which has been restricted to a single-location application, is not amenable to collaboration (Maher, et al., 1993; Mary Lou Maher, 1996), as the CAD system allows only one individual to view a drawing and to make changes in geometry. In fact, studies have shown the current CAD system is inadequate to model the various concepts that are present in multidisciplinary design situation (Kao & Lin, 1996; McKinney & Fischer, 1998; Rosenman & Gero, 1996).. To support a distributed design process, the collaboration system should combine the rich representation of a CAD with collaborative technologies such as video conferencing and application sharing to support a distributed design process (Chiu, 2002).

Designers can access CAD data that can be seen by each teammate (Maher, et al., 1993). As shown in Figure 2.5, CollabCAD allows multiple users to view same 3D object (Pečiva, 2007; Software, 1999-2009). It can also link video and audio channels so that users can see each other while communicating. Despite the fact that this CAD system offers for collaboration by providing more communication channels, it does not support multiple users to work simultaneously such as creating or manipulating a sketch or model on the same CAD drawing (Maher, et al., 1993).

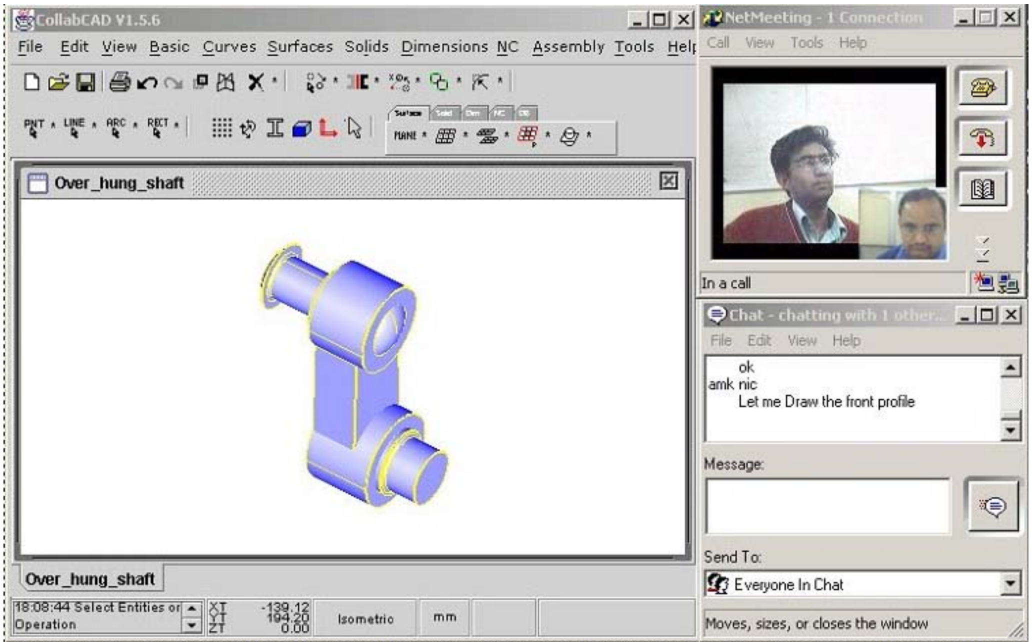


Figure 2.5 CollabCAD (Software, 1999-2009)

If design teams share a CAD file within a co-edit CAD system and even edit each other synchronously, the collaboration will be more effective than it will be exchanging CAD drawings by email.(Kao & Lin, 1998). Kao also argues that co-editing the three-dimensional CAD system will enhance collaboration in distributed design teams (Kao & Lin, 1996). The potential benefit of collaborative co-edit CAD system would reduce lead time to market, shorten product shipment time, so it will increase profit (Kao & Lin, 1996).

Computer-Mediated Communication (CMC) in Design

Another approach to collaborative communication that is used in design is the use of computer-mediated communication (CMC) technologies, which include email or instant messenger. These technologies are used for file exchange and sharing of models to support collaboration, such as proposing ideas on the development of a design, the exchanging archived information, and presenting ideas to others (e.g., clients) (Cramton, 2001; Cross, 2006). Indeed, CMC can support collaboration by facilitating communication, especially long distance communication (Maher, et al., 2000).

Table 2.1 shows the different types of CMC technologies in a space/time matrix. Since collaborative design activities must take place within a specific space and time, the patterns of collaboration differ according to four systems with different technologies: collocated synchronous, collocated asynchronous, remote asynchronous, and remote synchronous systems (Peng, 2001).

Table 2.1 Types of CMC technologies in a Space/Time Matrix

<table>
<tr><th></th><th>Synchronous
(Same time)</th><th>Asynchronous
(Different time)</th></tr>
<tr><td>Collocated
(Same place)</td><td>• Design meeting
• Brainstorming</td><td>• "Team room"
• "Shift work"</td></tr>
<tr><td>Remote
(Different place)</td><td>• Telephone
• Skype
o Video call (VoIP)
o IM
o File Transfer
o Video conferencing
• NetMeeting
o Video call (VoIP)
o Application sharing
o Chat
o Whiteboard
o File Transfer</td><td>• E-mail
• Blogs
• Text Message
• Voicemail
• Internet forum
• Wiki</td></tr>
</table>

Synchronous CMC (Real-Time Interaction)

Synchronous CMC tools allow immediate feedback from members of the design team, so they help teams to make quicker understanding (Gross, et al., 1998). In fact, on-line synchronous tools such as video conferencing, Instant messaging, and shared whiteboard all provide information about who is connected and available so that members may interact more (Peng, 2001), and they allow real-time communication and spontaneous interaction (Maher, et al., 2000).

The video conferencing enables a group of people to communicate and interact any time for any members who are in any places by overcoming the barriers of physical separation (Saad & Maher, 1996). One of the successful software of video call is Skype, which is a peer-to-peer Voice over Internet Protocol (VoIP) client developed in 2003 (Baset & Schulzrinne, 2006; Lisha & Junzhou, 2006). It allows multiple users to call over the Internet (as shown in Figure 2.6), and has also other features such as instant messaging, file transfer, and video conferencing. In fact, Skype was considered by some researchers the best application compared to any others such as Yahoo, MSN, and Google Talk (Baset & Schulzrinne, 2006).

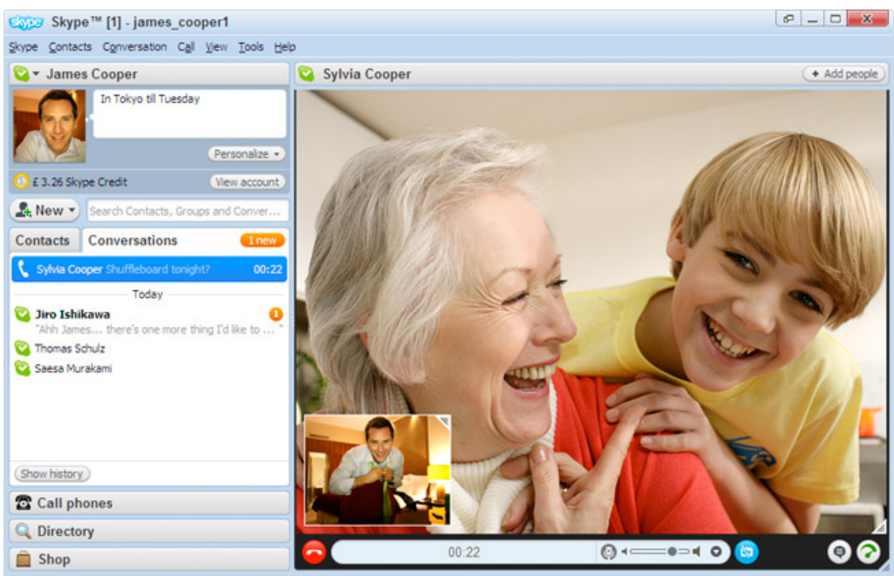


Figure 2.6 A Screenshot of Skype Video Call (Skype.com, 2009)

Even though Skype might be the best application for communication among users, it does not provide the important features such as Whiteboard for design collaboration. Microsoft NetMeeting is an integrated software which includes videoconferencing, whiteboard, application sharing, desktop sharing and file transfers, as illustrated in Figure 2.7, and it allows people who are distributed to "attend" meetings (Hinds, 2003). Instant messaging (IM) provides real-time text-based communication between users over the Internet. Whiteboard provides real-time graphic-based communication. Since drawing is fundamental medium for designers (Do, 1998; Landay & Myers, 2001; Lawson, 2004), being able to sketch together is necessary even when teams are distributed. NetMeeting Whiteboard allows teams to draw together to share ideas even while they are talking, illustrated in Figure 2.8. Furthermore, NetMeeting enables sharing applications between users so they are able to share any application, for example, 3D object sharing on a 3D CAD software, as illustrated in Figure 2.9.

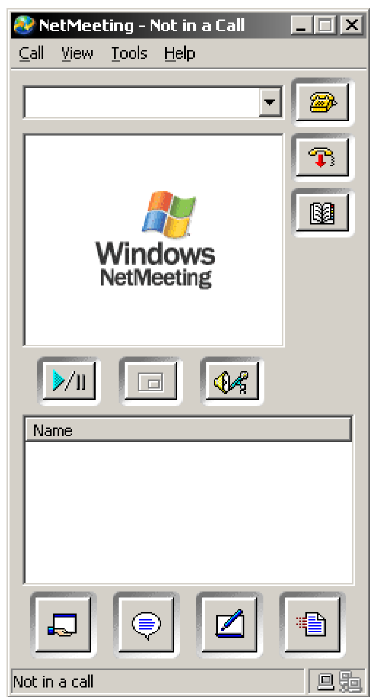


Figure 2.7 A Screenshot of the Microsoft NetMeeting for Windows XP

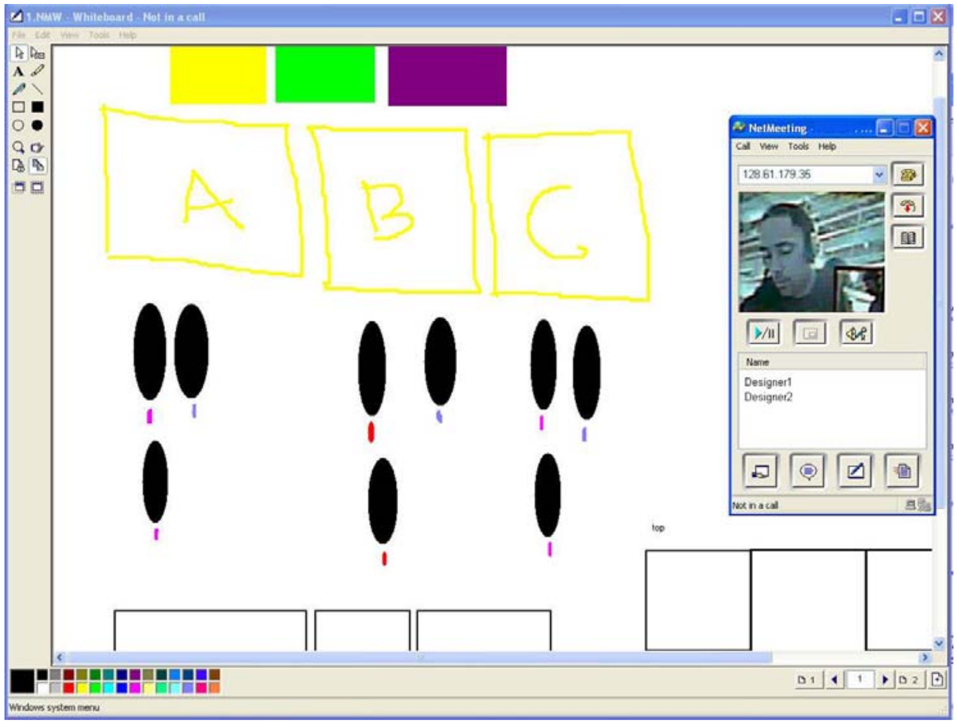


Figure 2.8 NetMeeting Whiteboard with Video Call

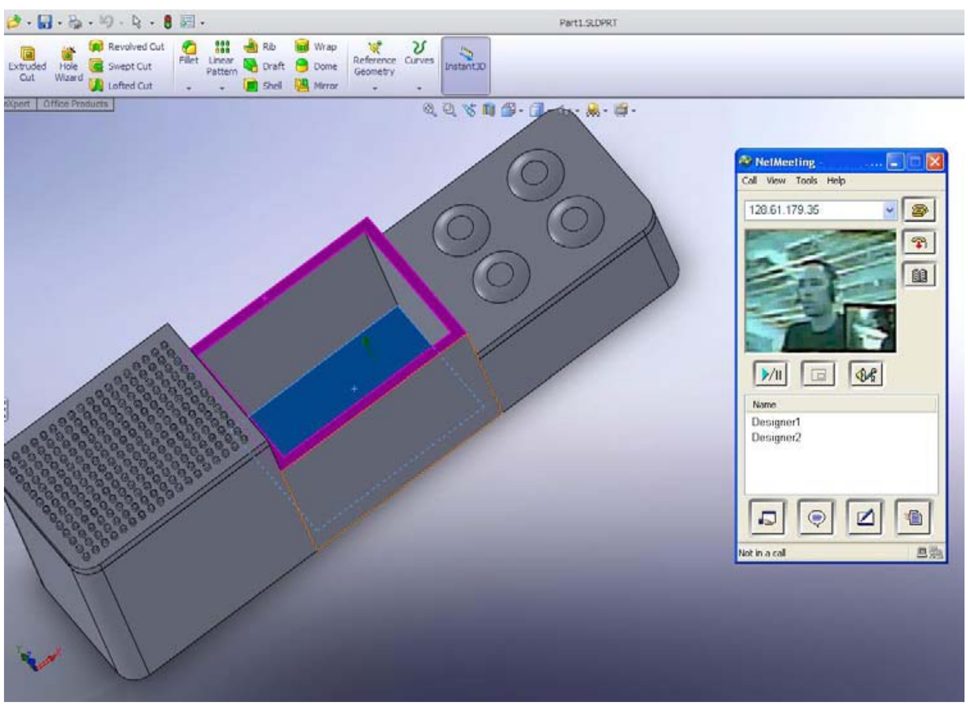


Figure 2.9 NetMeeting Sharing 3D CAD Program with Video Call

Despite providing great features for collaborative design, NetMeeting could benefit from further development since there still exists issues with the effective participation of users (Mark, 1999). Obviously, synchronous CMC provide faster and spontaneous interaction (Cheng & Kvan, 2000), so this synchronous collaboration might be the most obvious form for computer supported design collaboration (Gross, et al., 1998)

Asynchronous CMC (Non-Real-Time Interaction)

Although asynchronous CMC tools do not allow spontaneous interaction, they allow users to access of information when they have time and are more structured than a synchronous system (Peng, 2001). Collocated asynchronous collaboration presents indirect communication over a period time even though teams are located in the same location (Peng, 2001). Peng (2001) illustrates this collaboration as "team room" and "shift work". Teams are in the same physical places, but they pass information to the next shift.

In addition, asynchronous interaction allow individuals to work at their own space without interruption (Cheng & Kvan, 2000). Various software application support asynchronous CMC tools such as Email, Chat, and Wiki. Typically, long term asynchronous collaboration enables collaboration among designers, for example, in different time zones over the life cycle of a product (Gross, et al., 1998). In addition to having the flexibility in accessing information, asynchronous CMC tools' bandwidth requirement is very low (Maher, et al., 2000).

Collaborative Virtual Environments in Design

Another system that can support collaborative design is the collaborative virtual environment (CVE), which are online digital places and spaces where people can play and work together even they are distributed (Churchill, Snowdon, & Munro, 2001). CVEs support group activities that enable multiple users to meet as graphical embodiments called avatars and to see and experience the same virtual objects and virtual places (Churchill & Snowdon, 1998). According to Schroeder and Axelsson (2006), avatars play a significant role in CVEs because they embody the user in a shared space for interaction. In CVEs, multiple users see the same virtual objects in the same virtual places (Benford, Greenhalgh, Rodden, & Pycock, 2001; Churchill & Snowdon, 1998). The purpose of CVEs is to augment 3D space for collaborative work by enhancing the social experience (Benford, et al., 2001).

The main applications of CVEs to date have been military and industrial team training, collaborative design and engineering, and multiplayer games (Naughton, 2002). Many studies have noted that CVEs are increasingly being used to support collaborative activities, especially in distributed teams (Churchill & Snowdon, 1998). They are able to support synchronous activities such as the sharing of visual artifacts in real-time, a strong advantage that CMC technologies do not have, especially in collaborative design (Maher, et al., 2006; Maher & Simoff, 2000; Nederveen, 2007; Shaw & Swarts, 2008). Because sharing virtual space with others is essential to facilitating communication and collaboration, CVEs can enhance professional distributed design teams (Maher, et al., 2006). The CVEs are suited to group interaction because they are *multi-user, synchronous, navigable, embodied, and spatial* (Schroeder & Axelsson, 2006).

Collaborative Design in *Second Life*

One example of a popular virtual world in which multiple users can play over the Internet is *Second Life*. This virtual world allows multiple users to walk around the virtual environment and actively interact and view each others' avatars (Nederveen, 2007;

Research, 2009). Nederveen believed that *Second Life* could serve as a platform for multidisciplinary design and construction. In fact, many virtual buildings and structures have already been built by collaborative teams in *Second Life*. Nederveen found *Second Life* to be useful for such practices from three viewpoints: design, engineering, and collaboration. From a design perspective, it was very useful because people can look from all sides of an object and walk around it. *Second Life* is less useful from the engineering perspective because it contains no physical characteristics of the objects such as gravity, wind, or water flows (Nederveen, 2007).

Philips Design also considered *Second Life* as a great platform on which to engage residents in co-creation and to obtain a deeper understanding of potential opportunities in this virtual environment. The company is developing the concept of playful co-creation, which uses an immersive 3D environment of *Second Life* to create collaborative relationships (UgoTrade, 2008a). Figure 2.10 shows two designs of Philips Design—Co-creation Island and the Ideation Quest—in *Second Life* explores how to effectively combine the emerging technology of virtual worlds with a customer-centered perspective of open innovation. Their aim is to attract people from the *Second Life* community and introduce the island to people "as a place to cooperate and explore the future by design" (UgoTrade, 2008a).

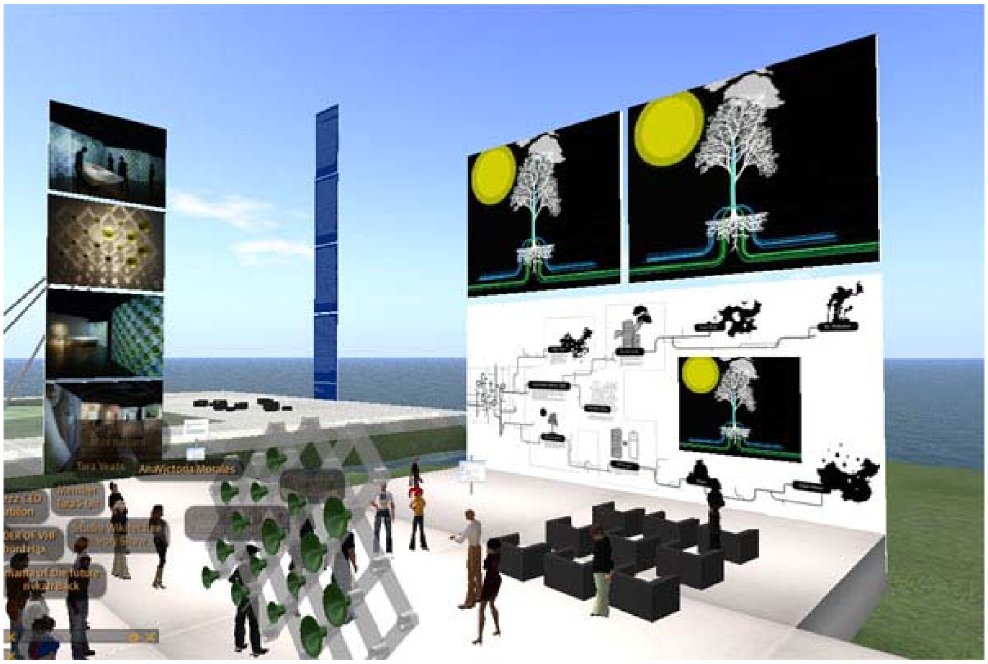


Figure 2.10 Philips Design's Ideation Quest in Second Life (UgoTrade, 2008b)

Second Life is powerful in encouraging group participation. Therefore, it represents a potential opportunity for interactive collaborative design in a virtual environment (Nederveen, 2007).

Collaborative Design in an Unreal Virtual Environment

Despite creating a great opportunity for collaborative design, *Second Life* has no import capabilities for 3D models created in other applications such as 3ds Max, Maya, or Sketch Up. In contrast, Unreal, a popular game engine, has import capabilities for a designer to create a 3D model using a modeling program such as 3ds Max and import that model into the Unreal virtual environment to show it to the other members of the design team. (Shiratuddin & Thabet, 2002). Game engines are originally developed for the rapid development of computer games. Architecture researchers have started to embrace game engines to visualize buildings (Dijkstra, Vries, Brosens, R.Hoekman, & Willems, 2001).

In addition, they consider the game engines as platforms for collaborative environment because users can propose and manipulate 3D form in a shared workspace while they are distributed in different physical locations (Moloney & Amor, 2003). They proposed that game engine based CVE can support the early stages of design where teams can communicate and collaborate.

The Unreal virtual environment was also introduced into the architectural design process in the Interactive Media Architecture Group in Education (IMAGINE) Lab at the Georgia Institute of Technology. Research scientists (Shaw & Swarts, 2008) from IMAGINE Lab found that the Unreal virtual environment had potential characteristics for nurturing a collaborative design environment as well as allowing designers to walk through their designed space. In addition, they found this Unreal virtual environment, as illustrated in Figure 2.11, offered the following advantages to users:

- Allowing multiple users to virtually work in real time in a shared workspace
- Experimenting with multiple designs
- Incorporating multiple vantage points
- Interfacing with specific information
- Providing an awareness of other users' view through the use of a virtual laser pointer
- Easily extensible through scripting via Unrealscript

Figure 2.11 A Screenshot of the Georgia Tech Campus in the Unreal Virtual Environment By the IMAGINE Lab

Another advantage of virtual environments is that they allow multiple, simultaneous input (see Figure 2.12). Modern operating systems allow only one input element on a computer screen to have focus at any given time. This effectively limits the collaborative capabilities afforded in running multiple applications on a single computer system. However, with shared files or applications running in a virtual environment each user is able to apply their own focus independent of any single controlling operating system (Shaw & Swarts, 2008).

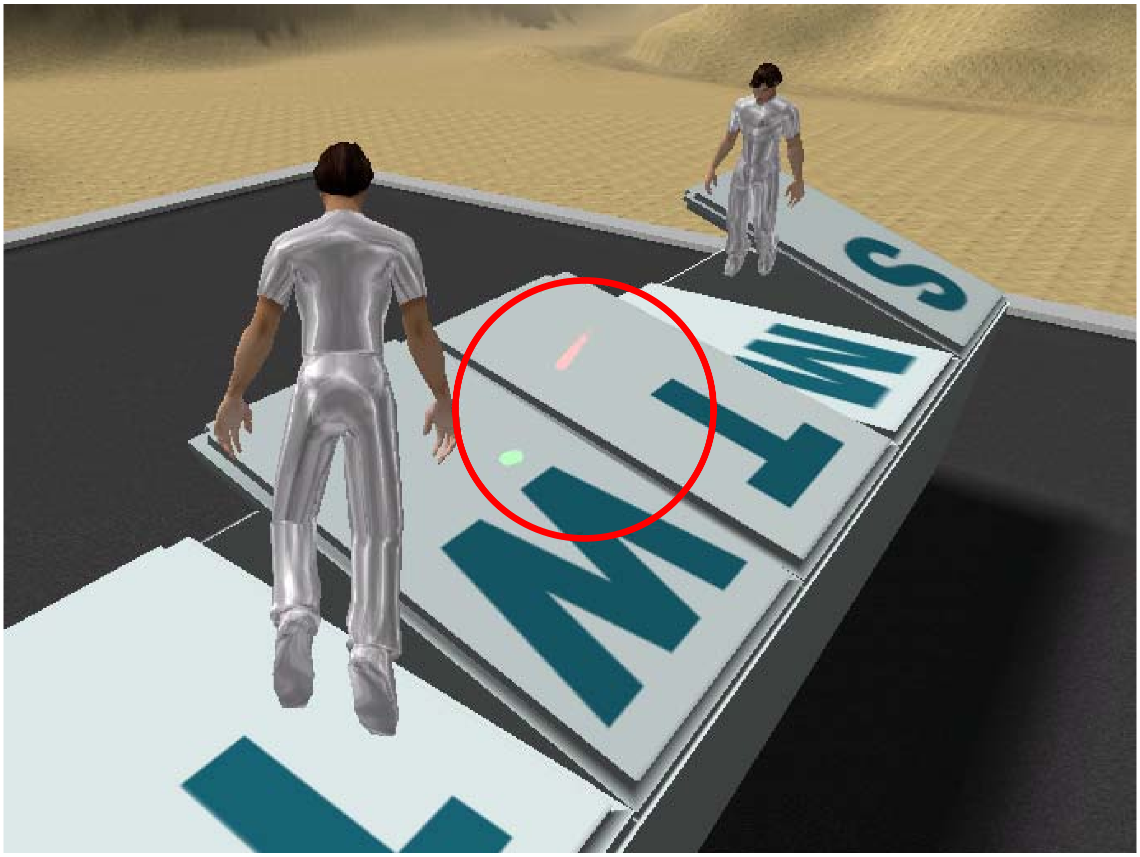


Figure 2.12 Two avatars with independent virtual laser pointers in the CVE (Unreal)

Summary

Although capable of communicating via CMC technologies and CVE, distributed teams exchange information less effectively than face-to-face teams (Lebie, et al., 1995). In addition, many software developers have attempted to develop CAD, CMC, and CVE for a multi-user model of a collaborative design environment in which designers do face-to-face synchronous design team activity (Maher, et al., 1993). However, little is known about why this is so and whether CMC technologies can meet the needs of design teams. There are many studies about distributed collaboration using CMC technologies in education and applications other than design collaboration (Redfern & Naughton, 2002; Sherry & Myers, 1998).

Because different computer-supported tools have different advantages and disadvantages, choosing the most effective tools at the right time can enhance design collaboration (Do, 1998; Maher, et al., 2000). This study will determine the extent to which design teams can communicate and collaborate in face-to-face and distributed environments using CMC and CVE, and what types of technologies help for design collaboration.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter describes an experiment that examined how designers in face-to-face and distributed settings collaborated through computer-mediated communication (CMC) technologies such as email or Instant Messenger, and collaborative virtual environments (CVEs) such as virtual reality and Computer Aided Design (CAD) software. The outcome of the comparison of the design teams in the two different settings was intended to provide insights into how one might design a better collaborative system.

Experimental Design

An experimental design session was used to study pairs of design students collaborating on two different tasks in both face-to-face and distributed settings, illustrated in Table 3.1. For Task 1, design team A was in the distributed setting and design team B was in the face-to-face setting. Design team A was in the face-to-face setting while design team B was in the distributed setting for Task 2.

Table 3.1 Experimental Design Session with Provided Tools of the Study

Task 1 (1 hour)		Task 2 (1 hour)
Team A (Distributed) Team B (Face-to-face)		Team A (Face-to-face) Team B (Distributed)
Provided Tools *Required to use Unreal in both face-to-face and distributed setting		
CMC	• Email • Skype • Instant Messenger (IM)	
CVE	• UnrealEngine2 Runtime 2226.20.02 (Unreal)	
CAD	• Autodesk® 3ds Max® 2009 32-bit (3ds Max) • Solid Works 2008 • Adobe Illustrator CS / CS2 (Illustrator) • Adobe Photoshop CS / CS2 (Photoshop)	
Others	• Pen and paper • Webcam and headset	

Participants

Participants included pairs of design students from the industrial design and architecture programs in the College of Architecture at Georgia Institute of Technology. Invitation form requesting participants is in Appendix A. All participants were male, three of whom were graduate students and one a 3rd year undergraduate student. All participants were familiar with the CMC technologies and CAD software used in the experiment, and they indicated they had experience using virtual shared 3D environments such as Second Life, VRML, and Kaneva.

Experimental Setup

The experiment took place in a Usability Lab equipped with four Internet Protocol (IP) cameras, commonly referred to as network cameras, at the Center for Assistive Technology and Environmental Access (CATEA) at the Georgia Institute of Technology.

Those four IP cameras; two capturing a bird's eye video of the participants and two focused on the screen of each participant, used for the observation of the participants' behavior, specifically their choices of tools. Figure 3.1 shows the Smart VS-IP Surveillance System monitor showing four different camera views for one design session.

Both teams collaborated in both face-to-face and distributed settings. The face-to-face setting, in which participants were seated next to each other and were able to talk and see one another, is illustrated in Figure 3.2. The distributed setting, in which the participants were located in the same room but with a panel separating them, simulating a distributed setting in which they were not able to see or talk to each other except via the CMC and the CVE technologies, is illustrated in Figure 3.3.

Communication and Design Tools

During a session, each designer was provided with a laptop with the Windows XP professional operating system and software available for the design tasks. Provided tools for designers are illustrated in Table 3.1. The CMC technologies included email, Skype, and Instant Messenger. The CVE was ARCH8803, a program built on top of the UnrealEngine2 Runtime 2226.20.02, and developed by the IMAGINE Lab at the Georgia Institute of Technology for the Introduction to Online Visualization Environments course in the College of Architecture. The CAD software included Autodesk® 3ds Max® 2009 32-bit (3ds Max), Solid Works 2008, Adobe Illustrator CS / CS2 (Illustrator), and Adobe Photoshop CS / CS2 (Photoshop), Email, Skype, and Instant Messenger.

Participants were also provided with traditional design tools such as pen and paper and digital communication tools such as a webcam and a headset. Researchers also let design teams use any other tools that were not listed in the Table 3.1 if they chose to do so.

Both teams were also given a 3ds Max file with existing products, a pill box and an extension cord. The models were placed in the Unreal virtual environment, as illustrated in Figures 3.5 and 3.6.

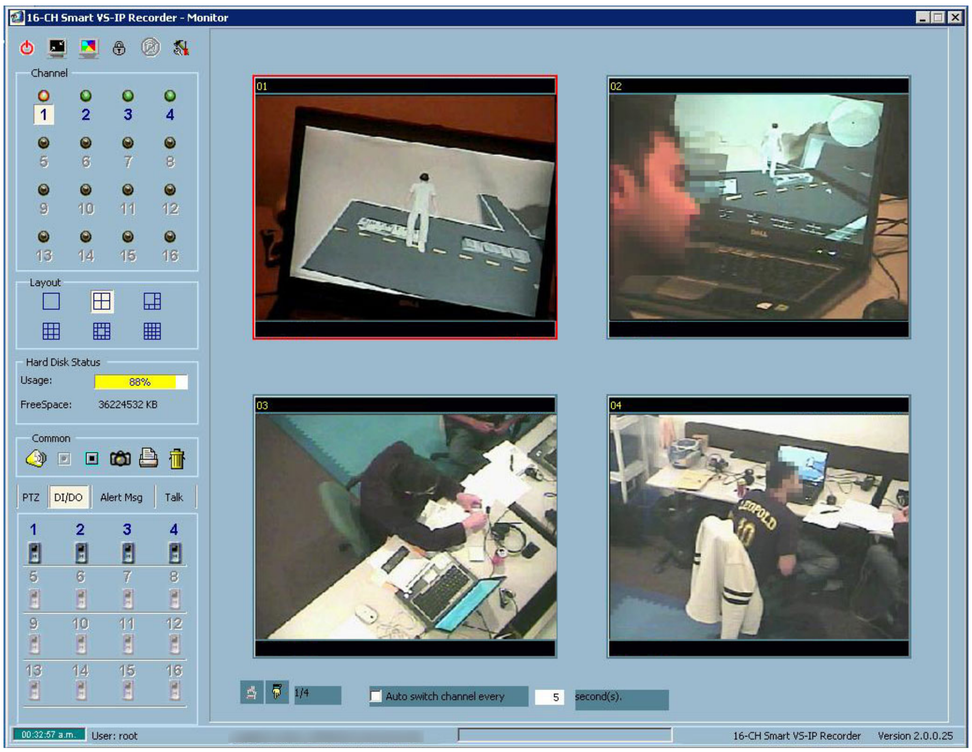


Figure 3.1 Monitor for the Smart VS-IP Surveillance System screenshot

Figure 3.2 Two design students collaborating in face-to-face setting

Figure 3.3 Two design students collaborating in a distributed setting

Procedure

Design students were randomly assigned to teams. Each team was asked to redesign two small products: 1) a pill box for a woman with mild memory loss and 2) an extension cord for a man with only one functioning hand. Both products were based on design problems, illustrated in Figure 3.4 that had been provided to the teams.

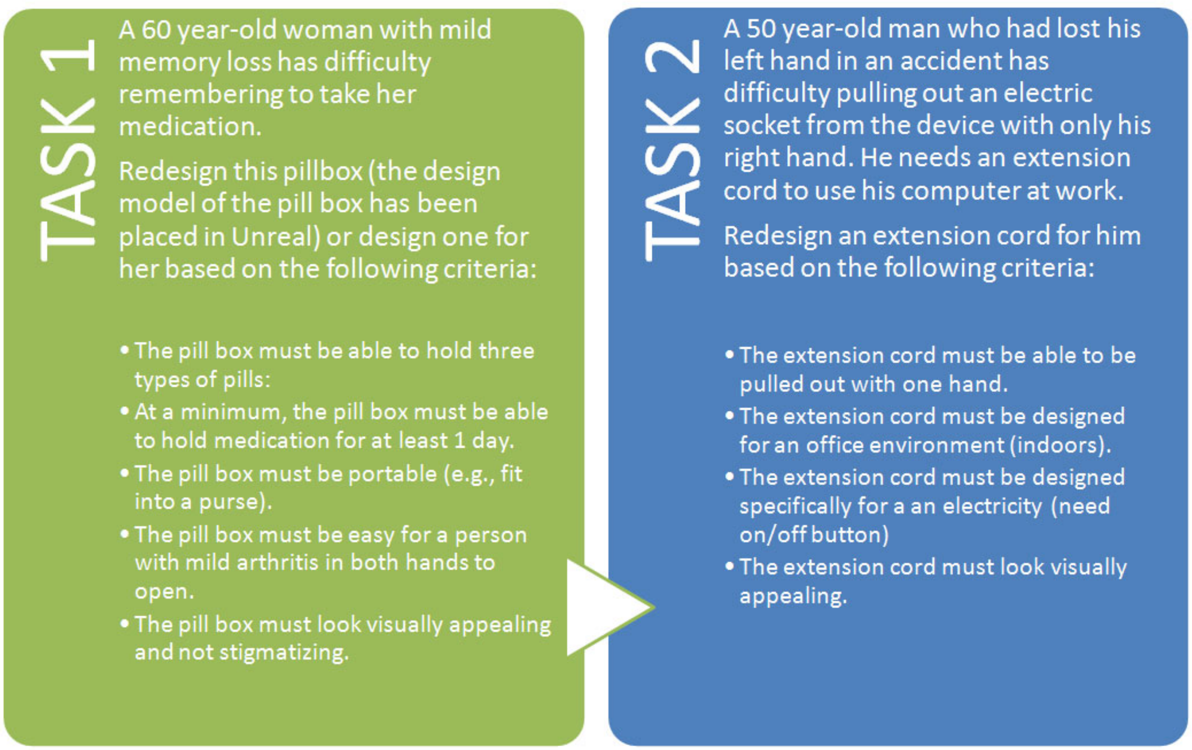


Figure 3.4 Descriptions of the Two Design Tasks for the Experiment

Teams were given Task 1 on the first day and Task 2 on the second day of testing, each task was asked to be completed within an hour. The full task descriptions are presented in Appendices D and E.

Task 1 in First Design Session Experiment

In the first design session, each participant was given an informed consent form and video release form, which were approved by the Georgia Tech Institutional Review Board (IRB). Both forms are available in Appendices B and C, respectively. Following the signing of the consent forms, participants were given time to practice using the available CMC technologies (e.g., email, Instant Messaging), CVE (Unreal), and CAD (e.g., Adobe Illustrator, Autodesk 3ds Max) on their computers. After the participants indicated that they were comfortable using the technologies available, they were given a instruction sheet (Appendix D) describing the design problem and requirements. For Task 1, design team A was in the distributed setting. Design team B was in the face-to-face setting. Both teams were also given a 3ds Max file with an existing product, a pill box; the model was placed in the Unreal virtual environment, illustrated in Figures 3.5.

Design teams had one hour to complete each task during which they were required to use the CVE (Unreal); however, they could choose any other tools they wished to use as well. When the design session experiment began, two observers went to the usability room and observed participants' behaviors, specifically their choices of tools and the design tasks in five minutes internal.

By the end of the hour, the team submitted a 16"x16" poster (pdf format) of their final design outcomes (see Table 4.2). Their original outcomes are available in Appendices Q,R, S, and T, respectively. The teams were provided with a template of the poster, which had been placed in a shared resources folder accessible from each participant's laptop. After finishing the design task, the participants were given a questionnaire that asked them to state their level of satisfaction, their expectations of collaborative work in face-to-face and distributed situations, the benefits they foresaw for the design process, and concerns they had about the communication tools. The questions were designed to gather users' experiences in the design session and their opinions about the design tools that they used. The participants rated their own design based on the following categories: the product (final outcomes), the design process, and the

Figure 3.5 Task 1: Pill Box in the Unreal virtual environment

design communication tools. They also answered open-ended questions about the CVE in the design process. The full questionnaire is available in Appendix H. At the conclusion of the first design session, the time and date for the second design session were set.

Task 2 in The Second Design Session Experiment

The second design session had a similar format to the first one. However, the design teams switched settings: design team A was in the face-to-face setting while design team B was in the distributed setting. In addition, the teams were asked to work on design Task 2, the extension cord. Given instruction sheet is provided in Appendix E.

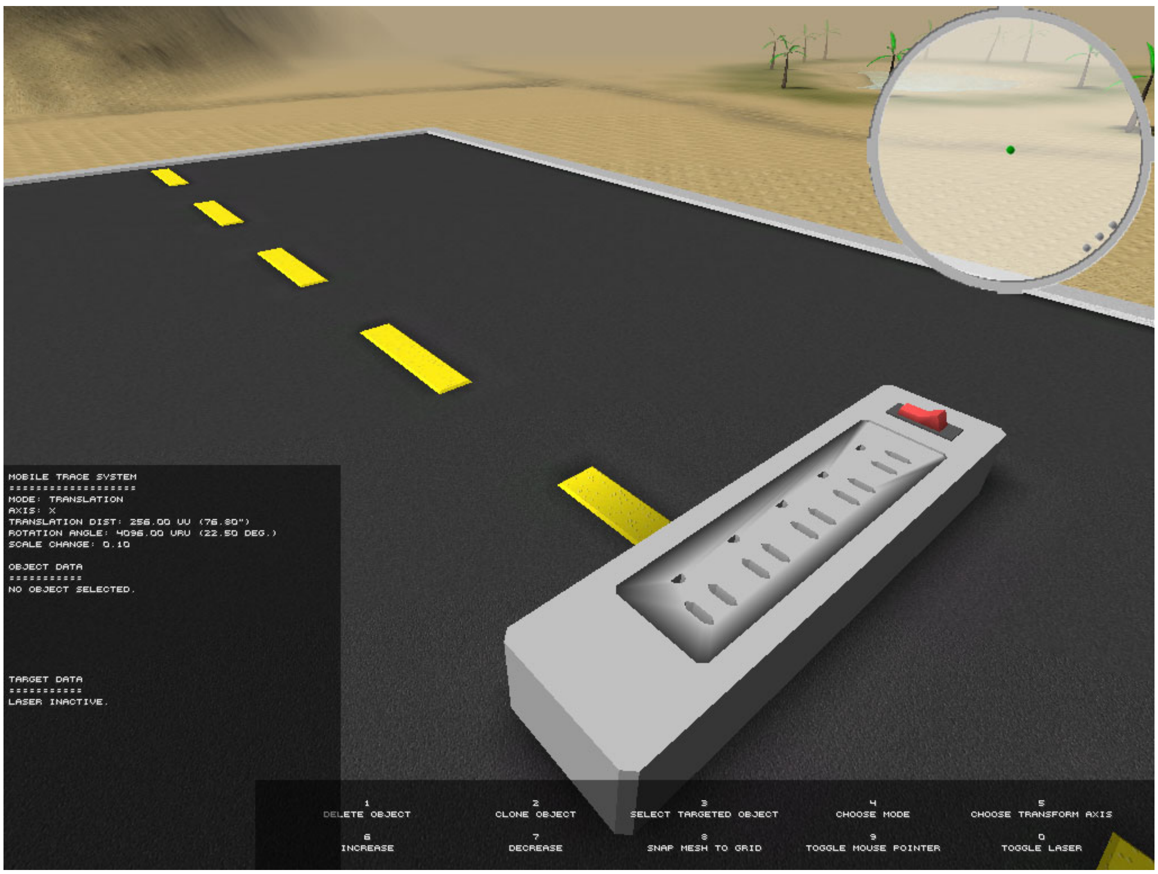


Figure 3.6 Task 2: Extension cord in the Unreal virtual environment

Similar to the first design session, both teams were also given a 3ds Max file with an existing product, an extension cord: the model was placed in the Unreal virtual environment, illustrated in Figures 3.6. The participants were given one hour to redesign the extension cord based on the provided requirements and to submit a 16” x 16” poster of their final design. At the conclusion of the design session and completion of the post-test questionnaire, identical to the one given at the end of the first design session, each design team was given additional questions to answer. The questions asked participants to compare their experiences of design Task 1 and those of design Task 2 in the two different settings. Additional questions are presented in Appendix I.

Video and Data Coding

The data from the two design sessions included four continuous streams of video and audio data. The stream of data for each session was segmented for coding and analysis using Observer XT 8.0 software. Coding behaviors and events within the design session used a coding scheme, a condensed version of which is presented in Table 3.2. Observer XT can record audio-video data and capture actions with time information. The Observer XT interface, which is capable of accessing the multimedia stream, and different coded events playing back and forth in one interface, illustrated in Figure 3.7.The protocol is segmented based on event occurrence and by time. An event changes when a different subject exhibits a different behavior. Observers focused on identifying design activities, the use of communication tools, and the working mode of the team members, working either together or individually, to determine the impact of the tools on the collaborative design process.

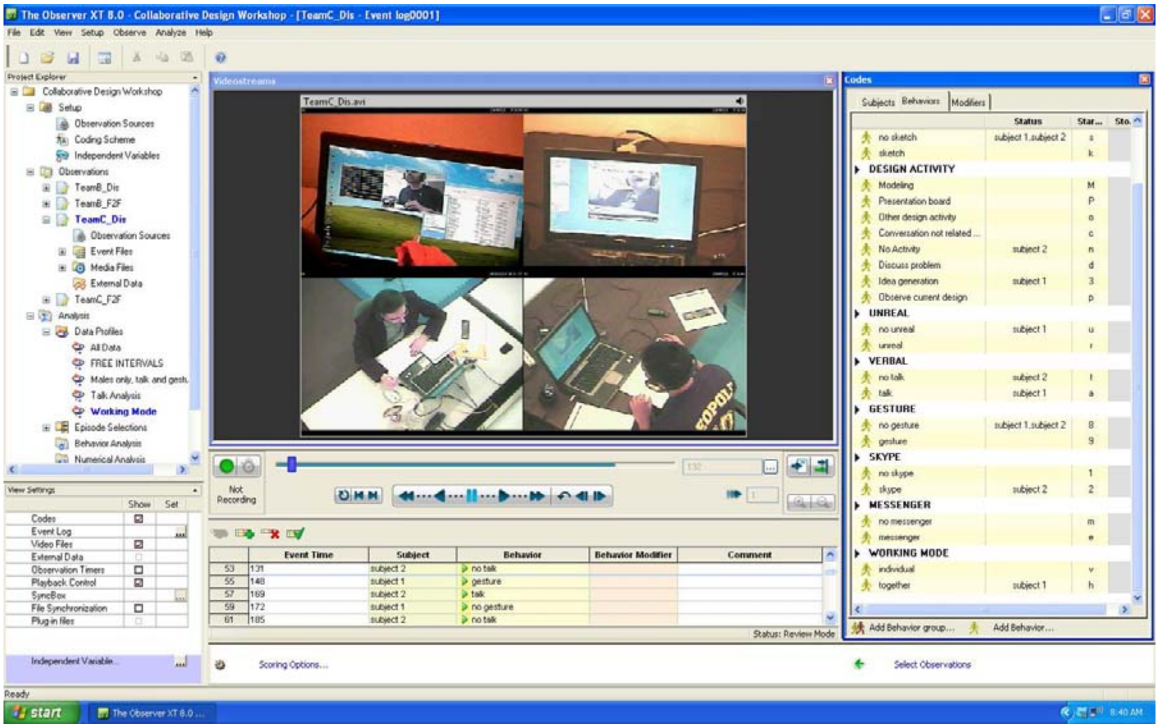


Figure 3.7 The Observer XT 8.0 Interface

Coding Scheme

Observers coded the behaviors of each team in both face-to-face and distributed settings. As shown in Table 3.2 coding scheme was developed to categorize design activities, the use of communication tools, and the working mode. For design activities, observers coded the behaviors of problem discussion, idea generation, and 3D model observation of the current design as a team processes because participants were working together for these design activities. Meanwhile, design activities such as sketching, modeling and preparing presentation board were coded for each designer separately because they performed those individually. In addition, observers coded the kinds of communication tools used by the teams during the design session. Talking, gesturing, and the use of Instant Messenger (CMC), Skype (CMC), and Unreal (CVE) were considered as communication tools while designers collaborated in both settings.

The study also focused on how much time teams worked in the "together" mode. The coding scheme follows Kvan’s definition (Kvan, 2000) of collaborative design as a "closely coupled" or "loosely coupled" process. In this study, the "together" code refers to when designers communicate and share design information about their design, and “individual" code refers to when designers work on different tasks individually.

The program Observer XT was used to code the video and audio recordings of the design sessions. After coding each segment, Observer XT provided integrated visualization data showing what the two participants were doing and what design activities and tools they were using over the course of the design session (Figures 4.1, 4.2, 4.3, and 4.4).

Table 3.2 Coding Scheme for the First Study

WHO	
Face-to-Face Team A / Team B	**Distributed** Team A / Team B
WHAT	**Design Activity**
Discuss problem	Clarify meaning of design problem
Generate ideas	Propose and share a new idea/concept/design solution
Observe current design	Discuss/analyze the current design
Discuss design details	Discuss detail such as dimension/ texture
Modeling	3D modeling and rendering for proposed design
Presentation board	Prepare for the poster that shows the design concept
Other design activities	Conversation about software/application features
Not related to the task	Not related to the task
HOW	**Communication Tool**
Talking	Verbal communication
Gestures	Non-verbal communication
Sketches	Sketch on paper
Email	CMC
Chat	CMC tool such as IM
Video Chat	CMC such as Skype with webcam
Unreal	CVE
WORKING MODE	
Together	Meeting and sharing the proposed design
Individual	Working individually on the proposed design

CHAPTER 4

RESULTS

Observational Data

This chapter analyzes and interprets the results of the first study. Teams showed similar patterns of design activities in both the face-to-face and distributed settings. However, they used communication tools very differently in the settings.

In the first session, Team A (subject 1, subject 2) started to work in the distributed setting first for Task 1. Figure 4.1 shows the work process of Team A distributed by time. Team A discussed the design problem, observed the current design, and generated design ideas together for about 43 minutes (see Figure 4.1). The red bar shows "together" mode, and blue bar shows "individual" mode. After the members of Team A decided on a proposed design, they separated all the different design tasks such as 3D modeling for subject 1 and 2D graphic work for subject 2. For the duration of the rest of the time of the design session, they worked individually and put the design together at the end of the session. They used Skype to communicate with each together during the entire design process, but they also used Unreal for about 15 minutes , as shown , as illustrated in Figure 4.2. (see Appendix M for a larger diagram) to observe the current design (pill box) and brainstorm ideas together.

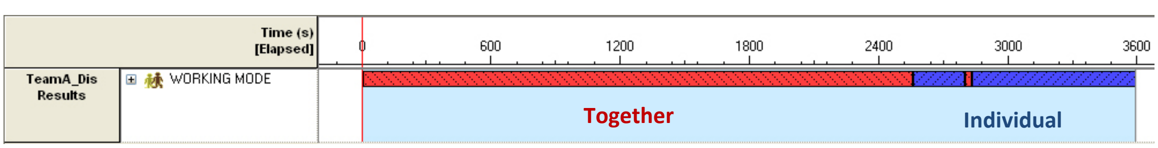


Figure 4.1 Team A's Working Mode (Task 1: Distributed)

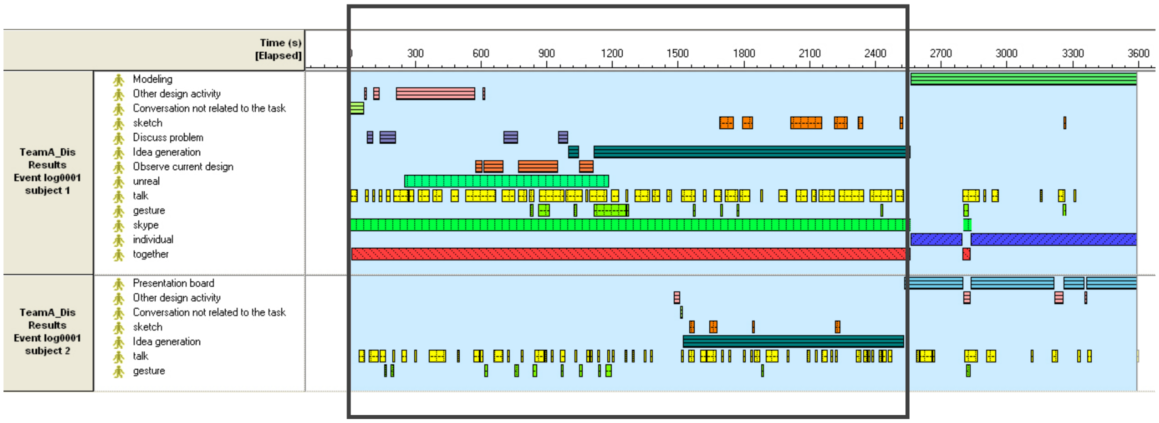


Figure 4.2 Team A (Task 1: Distributed)

Team B (subject 3, subject 4) had the same design task but in a face-to-face setting. Figure 4.3 shows Team B's face-to-face work process by time (see Appendix N for a larger diagram). The members of Team B came up with their proposed design idea in about half an hour (see Figure 4.4). They exhibited a pattern similar to that of Team A, in which they divided the work into separate design tasks: one person did the 3D modeling for subject 3 while the other did the 2D graphic work for subject 4. However, Team B created their design idea more quickly than Team A. They did not use any other CMC tools because they were able to see each other and talk face-to-face (see Figure 3.2).

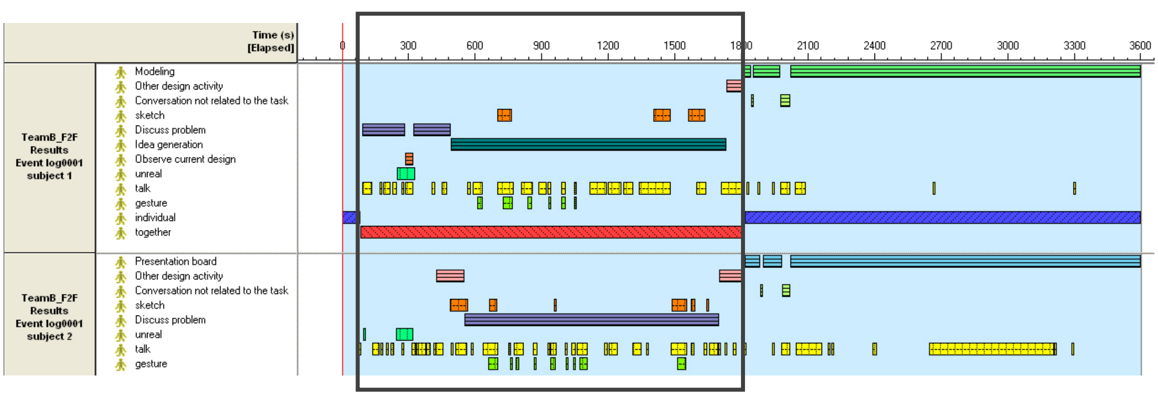


Figure 4.3 Team B (Task 1: Face-to-face)

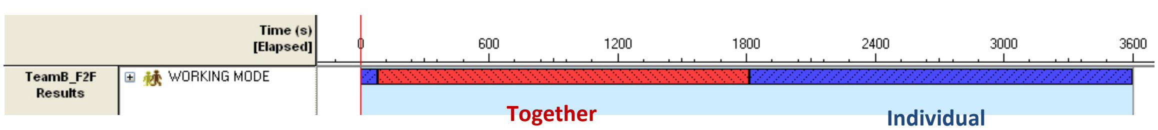


Figure 4.4 Team B's Working Mode (Task 1: Face-to-face)

In the second design session, each team had a different task in a different setting than in the first session. Figure 4.5 shows Team A's face-to-face work process by time (see Appendix O for a larger diagram). During this time, Team A was able to get their proposed idea much more quickly than they did in the first session, coming up with a proposed design together in about 20 minutes and then working individually the rest of the time, as shown in Figure 4.6.

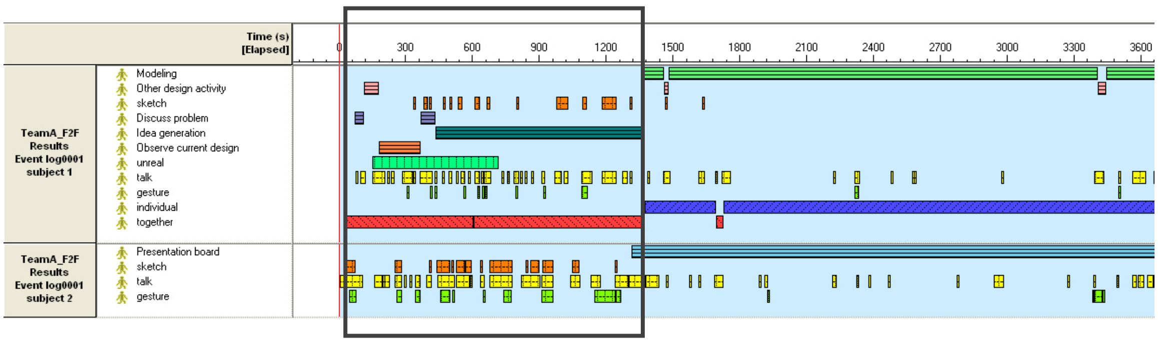


Figure 4.5 Team A (Task 2: Face-to-face)

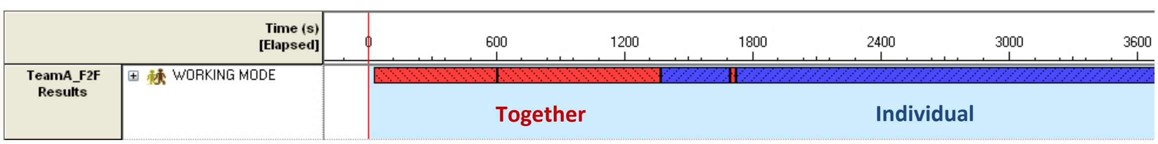


Figure 4.6 Team A's Working Mode (Task 2: Face-to-face)

Team B performed design Task 2 in a distributed setting in the second session. Even though Team B were in a distributed setting, they performed more quickly than they did in the face-to-face setting. Figure 4.7 shows (see Appendix P for a larger diagram) Team B's work process in the distributed setting by time. Team B started to work together for about 25 minutes, and they divided work to work individually. However, they worked individually even when they generate ideas. After sketching their own ideas, they shared ideas using webcams. Team B also put their model into Unreal to talk about their proposed design.

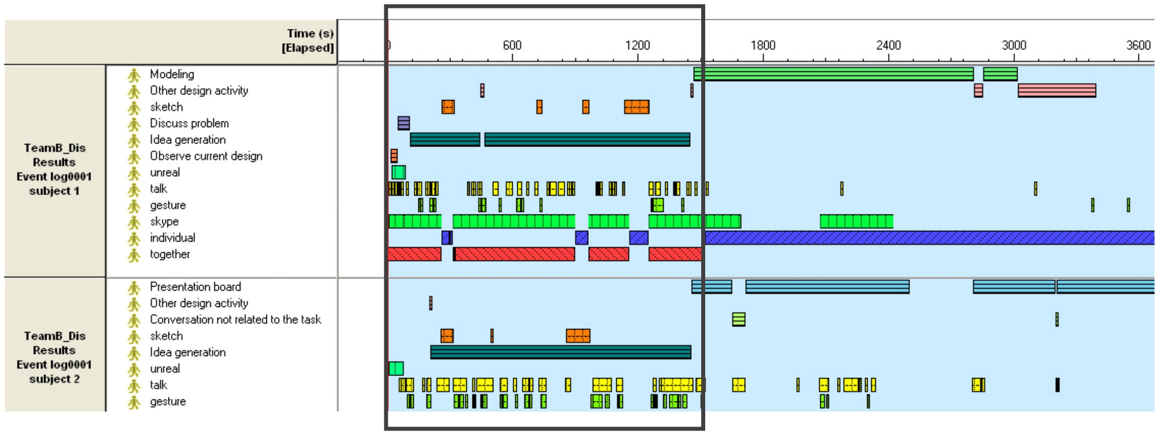


Figure 4.7 Team B (Task 2: Distributed)

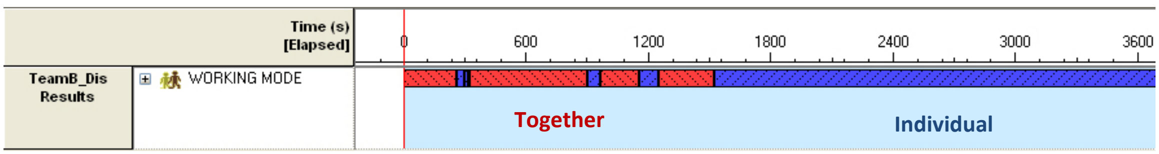


Figure 4.8 Team B's Working Mode (Task 2: Distributed)

Design Activities

One of the main categories of the coding scheme was identifying teams' design activities such as idea generation, sketching, and modeling. In both the face-to-face and distributed settings, design teams showed similar patterns of design activities. Figure 4.9 shows the percentage of time each team spent on each design activity in the face-to-face setting. In both settings, they discussed the problem, observed the current design, and generated ideas through discussions and sketches at the beginning of the design process. Following these activities, they divided the work into separate tasks: one designer did the 3D modeling (subject 1 from Team A, subject 3 from Team B) and the other did the 2D graphic work (subject 2 from Team A, subject 4 from Team B) for the presentation board. Figure 4.10 shows the percentage of time each team spent on each design activity in the distributed setting. Like in the face-to-face setting, the teams used a similar process of discussing the problem and generating ideas together until they came up with a proposed design; then they separated the different tasks such as modeling. On each team, one designer did the 3D modeling (subject 1 from Team A, subject 3 from Team B), and the other did the 2D graphic work (subject 2 from Team A, subject 4 from Team B) for the presentation board.

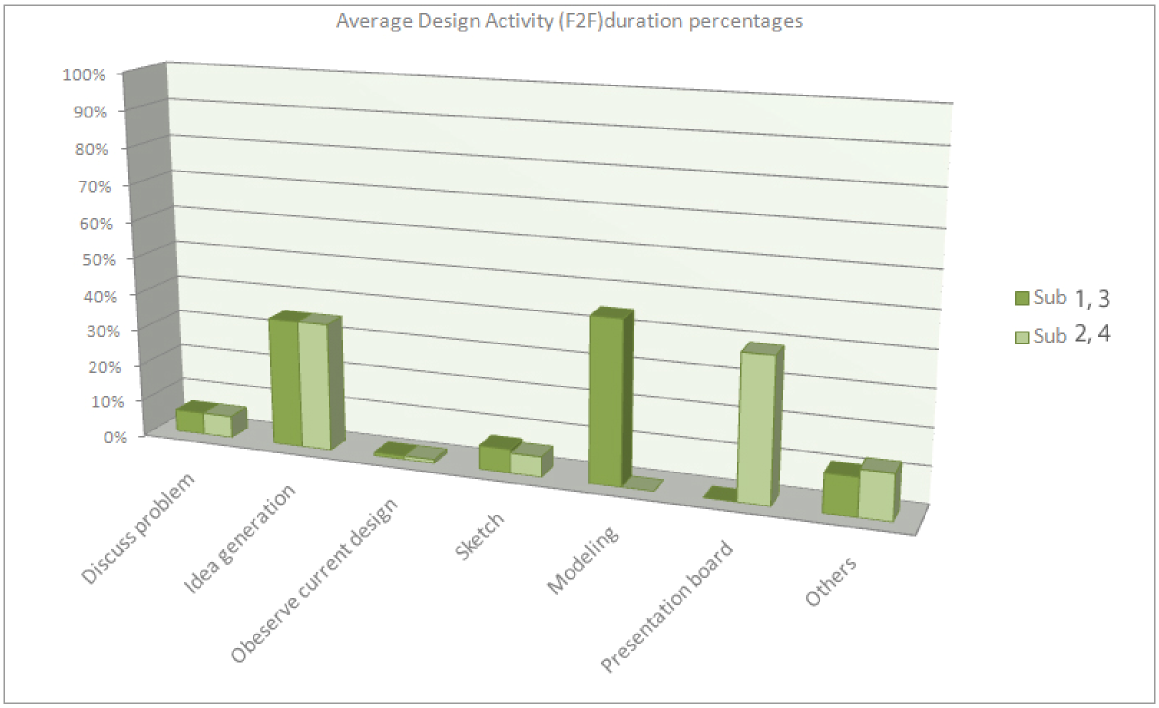


Figure 4.9 Average Design Activity (Face-to-face)

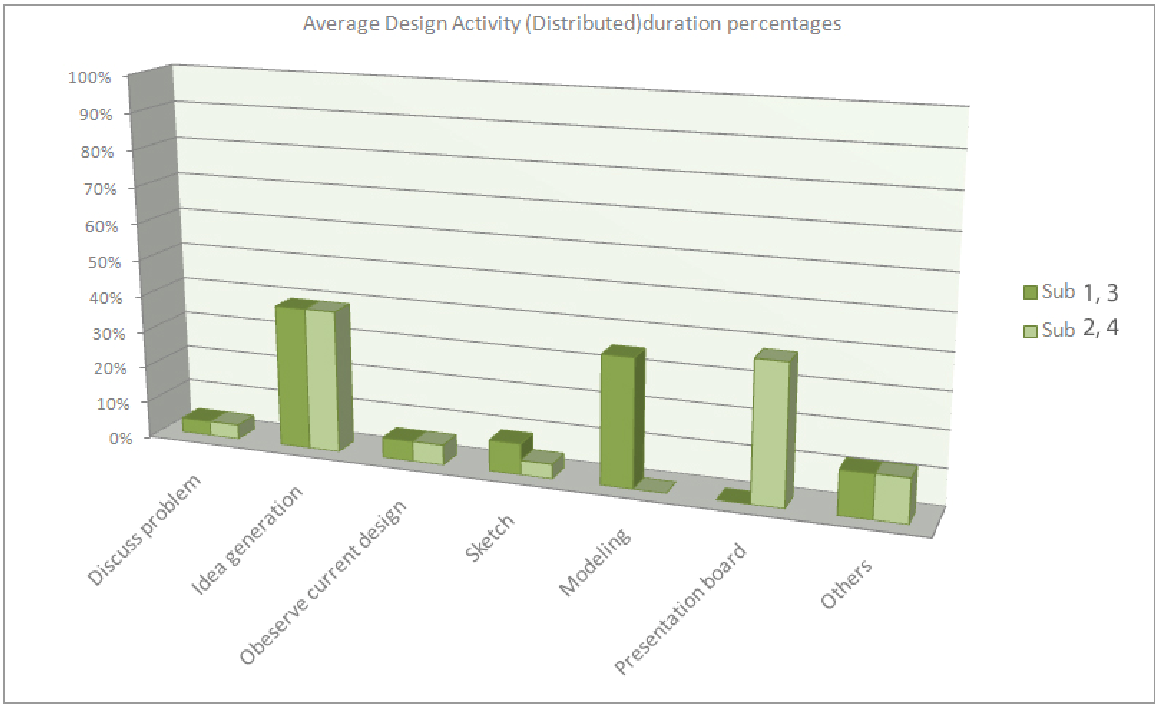


Figure 4.10 Average Design Activity (Distributed)

Use of Communication Tools

Because the design tasks were team projects, participants needed communication tools to achieve agreement in the design process. Even though the two teams in the different settings exhibited similar patterns of design activities, they used different communication tools in each of the two settings. Figure 4.11 shows the percentage of time each team used with each communication tool in the face-to-face setting. Among communication methods, designers used verbal communication (i.e., talking) most often to share their ideas. Gestures also played a large role in their design communication when they were talking or showing their sketches. Because they were able to see and talk to each other face-to-face, they did not use CMC technologies. However, in the distributed setting, they used CMC technologies to share and discuss the design ideas. Figure 4.12

shows the percentage of time each team used each communication tool in the distributed setting.

Both teams used Skype during about 70 percent of the entire design process. Skype allowed them to talk and even see each other by video call. They used Unreal to view, move around, and observe the existing products within the Unreal virtual environment (See Figures 3.5 and 3.6 for screenshot of the Unreal virtual environment). However, they used Unreal less than 10 percent of the time because they could not design and manipulate the objects in the Unreal virtual environment at the same time. In addition, they never used e-mail as a communication tools in this setting; only one team member used Messenger and only once to send the shared white board link address to his teammate.

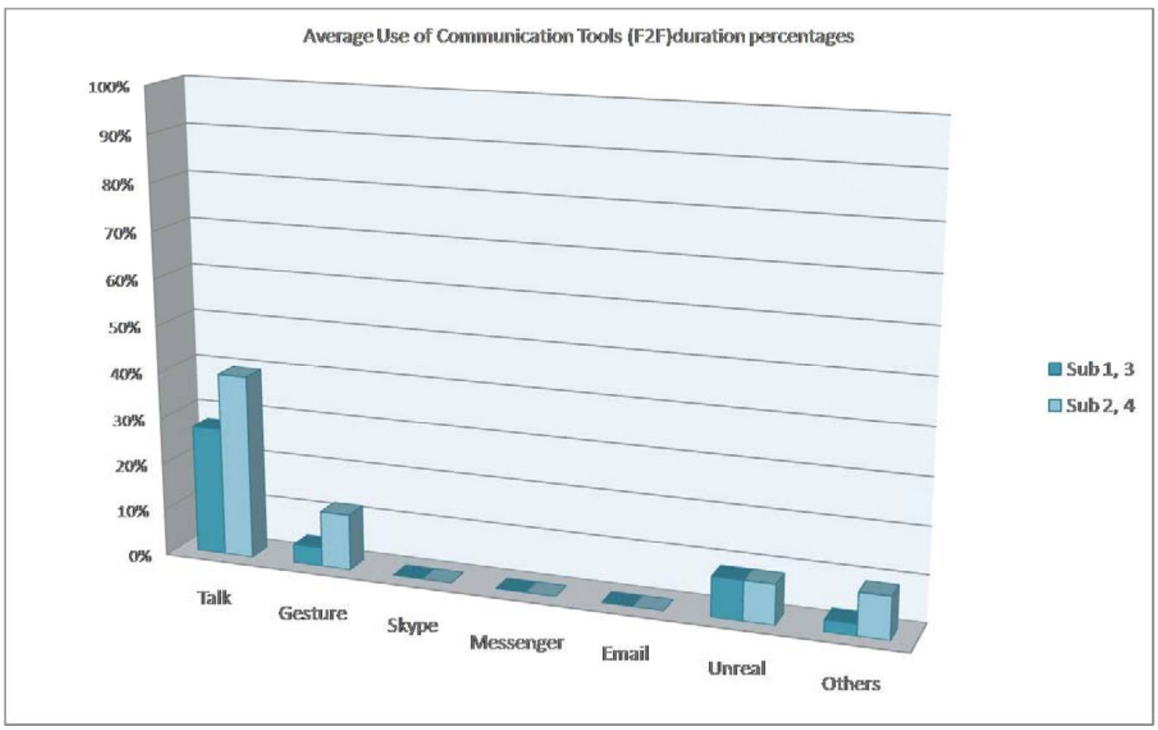


Figure 4.11 Average use of communication tools (face-to-face)

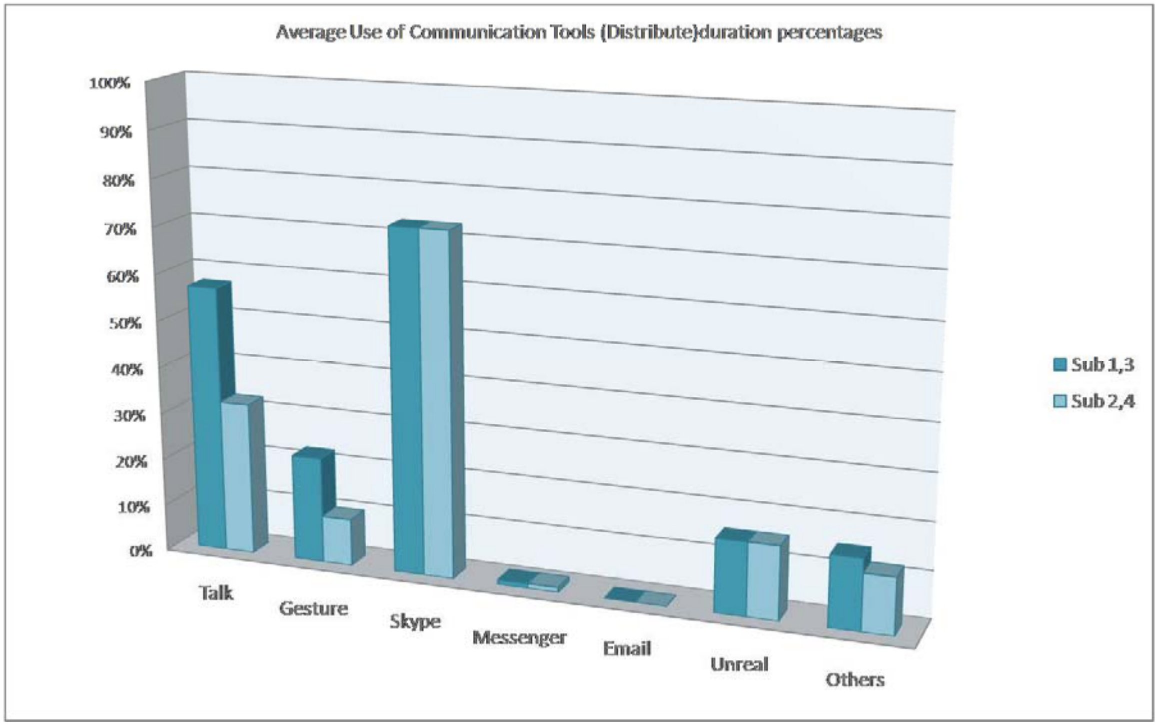


Figure 4.12 Average use of communication tools (distributed)

<u>Use of Other Communication Tools</u>

Only Team A used a online shared whiteboard, which allowed designers sketch together. We did not provide a shared whiteboard for this workshop, but Team A thought they needed and they used a online shared whiteboard. Teams allowed to use any other tools if they needed. Team A used this shared whiteboard to share their sketches, and this shared whiteboard gave them the ability to illustrate their ideas with drawings for one another synchronously.

However, Team B shared another way to share their sketches. They used their webcams to share, view each others' sketches. Figure 4.13 shows designers sharing their sketches using a webcam by pointing it at the screen.

Figure 4.13 Sharing sketches using a webcam (Team B)

Both teams used webcams in unconventional ways for sharing design information for design process. Team A used the webcam for sharing their 2D/ 3D graphic models by pointing it at the screen, as shown in Figure 4.14. Sharing screen images appeared to be an important part of the communication process.

Figure 4.14 Sharing 2D/3D graphics using a webcam (Team A)

When the participants showed their visual information, either sketches or 3D models, they asked for the other person's opinions with questions such as "Is this okay?" or "What do you think about the shape?" Because this session was a team project, they needed the communication tools to achieve agreement in the design process.

Working Mode

After agreeing on a proposed design, both teams divided up the various design tasks to produce a concept design. However, each team in each setting exhibited different behaviors relating to how much time they worked together and individually. Figure 4.15 shows the percentage of time each team in each setting worked together and individually.

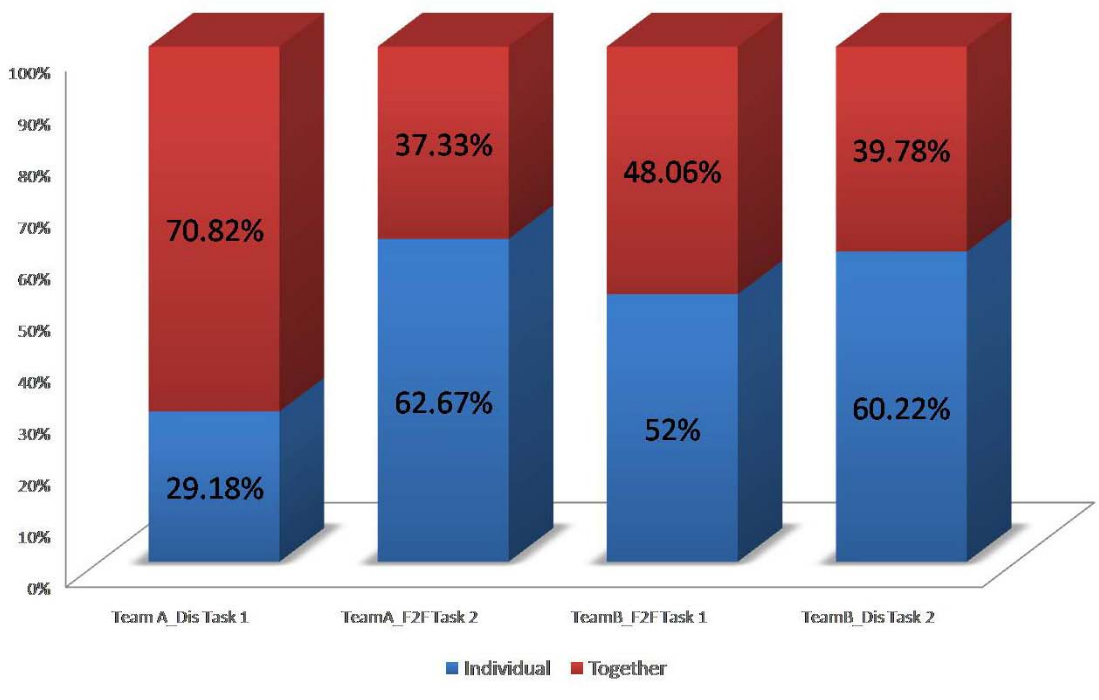


Figure 4.15 Working modes (together/individual)

Team A worked together about 70 percent of time and individually for about 29 percent of their time in distributed setting. However, Team A worked together about 37 percent of time and individually for about 62 percent of their time . in the face-to-face setting,. This team worked together about 33 percent more in the distributed setting than in the face-to-face setting: together.

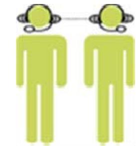
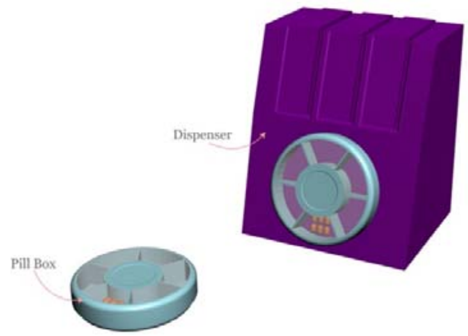
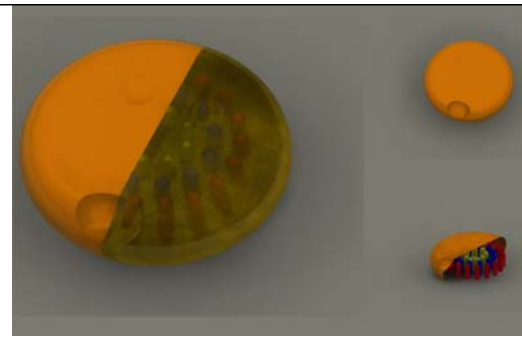
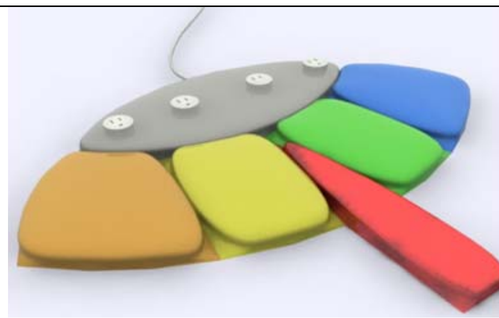
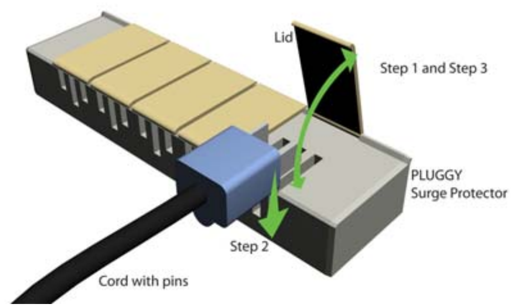
In contrast, Team B worked together more in the face-to-face (48 percent) than in the distributed (40 percent) setting. Team B worked together about 48 percent of time and individually for about 52 percent of their time in face-to-face setting. However, they worked together about 40 percent of time and individually for about 60 percent of their time in the face-to-face setting.

Both teams worked together more in the first session than in the second session whether in face-to-face or distributed settings. Thus, the team was able to come up with a design idea more quickly than it did the first time and to start working individually sooner.

Design Outcomes

The design teams provided the final design outcomes of Task 1 and Task 2 in a 16” x 16” pdf file by the end of the two design sessions. Table 4.1 shows each team's final design rendering of Tasks 1 and 2. The final design outcomes with project descriptions are provided in Appendices Q, R, S, and T.

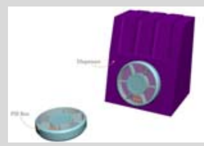
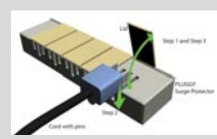
Table 4.1 Final Outcomes of Team A & B

	 FACE-TO-FACE	 DISTRIBUTED
TASK 1	 Team B	 Team A
TASK 2	 Team A	 Team B

Evaluation of the Final Outcomes

Two faculty members from the College of Architecture who had not observed the design sessions and were blinded to team assignment and setting, evaluated the final designs of each team. First, the faculty members were given the design criteria of each task and time to read them. Then they evaluated each of the four final designs based on the evaluation criteria (See Appendices K and L). Table 4.2 shows the final grade assigned to each design by the two evaluators. The grades, reported in Table 4.2, were, contrary to what was expected, the designs created in the face-to-face setting were not graded higher than those created in the distributed setting.

Table 4.2 Evaluation of Each Team's Design

			
TASK 1		 Team B	 Team A
	Evaluator 1	C+	B+
	Evaluator 2	C-	A
TASK 2		 Team A	 Team B
	Evaluator 1	A-	A
	Evaluator 2	A+	A

Questionnaires

In addition to the observation of the teams' design process, the results of the questionnaires provided interesting insight into how satisfied the teams were of their design in the face-to-face and distributed settings. Table 4.3 shows the results of the self-evaluation of the participants in the face-to-face setting. As the results show, most received high evaluation scores (8-9) in terms of overall interactions of the team, the quality of product, and the use of communication tools. However, one participant was not satisfied with his ability to collaborate with is teammate because he did not approve of his teammate’s using Illustrator for the 3D model. In addition, he was not satisfied of using communication tools because he thought he rarely used the communication tools. he said that "we talked and sketched". Thus, in his view, working on the different tasks was not a collaborative process.

Table 4.3 Self-Evaluation Results of the Participants (a total of four) in the Face-to-face setting

	Poor									**Excellent**
	1	2	3	4	5	6	7	8	9	10
Overall										
How well you think **you** did during the design session, focusing on the quality of the final outcome?							1		2	1
How well do you think **your teammate** did during the design session, focusing on the quality of the final outcome?								1	2	1
How well you think **your team** did during the design session, focusing on team effectiveness?								3		1
Product (outcome)										
Quality					1			1	2	
Level of productivity							1	1	1	1
Efficiency										
Process							1		3	
Ability to collaborate with your teammate		1						2		1
Ability to communicate with your teammate								1	2	1
Tools										
Ability to use communication tools		1				1			2	

Table 4.4 shows the result of participants' self evaluation for the distributed setting. The numbers represent the number of participants who gave each rating. Like the evaluation

in the face-to-face setting, teams rated themselves high in terms of their design process, final outcomes, and communication.

Table 4.4 Self-Evaluation Results of the Participants (a total of four) in the Distributed Setting

	Poor									**Excellent**
	1	2	3	4	5	6	7	8	9	10
Overall										
How well you think **you** did during the design session, focusing on the quality of the final outcome?							1	3		
How well do you think **your teammate** did during the design session, focusing on the quality of the final outcome?								2	2	
How well you think **your team** did during the design session, focusing on team effectiveness?								2	2	
Product (outcome)										
Quality							1	1	1	1
Level of productivity								3	1	
Efficiency										
Process							2	2		
Ability to collaborate with your teammate						1	2		1	
Ability to communicate with your teammate							1	1	2	
Tools										
Ability to use communication tools								1	3	

Teams gave different ratings for the technology in terms of sharing design information. As Table 4.5 shows, participants did not use as much technology in face-to-face setting because they could talk in person. We provided Unreal and required to use design teams. Team B thought they did not use it because they were just moving through in Unreal virtual environment. They mentioned Unreal was not useful because it lacks the ability for sharing ideas, they could not manipulate in Unreal virtual environment. However, One participant from Team A rated high for Unreal because he liked that he was able to visualize the current model (see Figure 3.6) for proposing ideas. Another one Team A said the laser pointer was less effective when they share the model because he could point to the actual screen in face-to-face.

Table 4.5 Self-Evaluation Results of the Participants Regarding the Effectiveness of CMC and CVE in the Face-to-Face Setting

	Poor									**Excellent**	**Didn't use it**
	1	2	3	4	5	6	7	8	9	10	
CMC technologies											
Email											4
Messenger											4
Skype											4
CVE											
Unreal			1						1		2

However, participants rated Skype the most effective tool in the distributed setting compared to the CMC and CVE technologies. As Table 4.6 shows, they highly rated the use of Skype as a design communication tool in the distributed setting. Compare to Skype, Unreal was not highly rated. One designer from Team B said it is great for visualization but lacks communication tools such as voice, shared drawing. Another designer form Team B, who rated Unreal very poor, said "we did not use Unreal to design", "we only used this to understand and what the power cord was". However, Team A was more satisfied using Unreal than Team B. One from Team A liked Unreal because it enables multiple people to view, sit, fly around a model to talk about it in a virtual environment. In addition, one from Team A mentioned the laser pointer was helpful in conveying what I was referring to on the model (as shown in Figure 2.12), but the game takes the whole screen, they could not use Skype video chat and Unreal together.

Table 4.6 Results of the Self-Evaluation of the Participants Regarding the Effectiveness of CMC and CVE in the Distributed Setting

	Poor									**Excellent**	**Didn't use it**
	1	2	3	4	5	6	7	8	9	10	
CMC technologies											
Email											4
Messenger								1	1		2
Skype							1	1	1	1	
CVE											
Unreal		1		1			1		1		

Additional Questionnaires

After the second design session, participants were asked to compare the two working settings. The four questions and the participants' responses are presented in Figure 4.16. The provided question sheet is in Appendix H. The participants were asked to explain why they believed one setting was better than the other. They mentioned that the differences were due to the different tasks rather than the different settings. All the participants thought that face-to-face communication was more conducive to sharing design information; and they simply preferred face-to-face to distributed communication. However, 75 percent of the participants (3 out of 4) felt that they more engaged in working with their teammate in the distributed setting. Participants said that " forced to be engaged because otherwise there is zero communication", "forced to communicate better", and "concentrated more in distributed using hand gestures using a webcam."

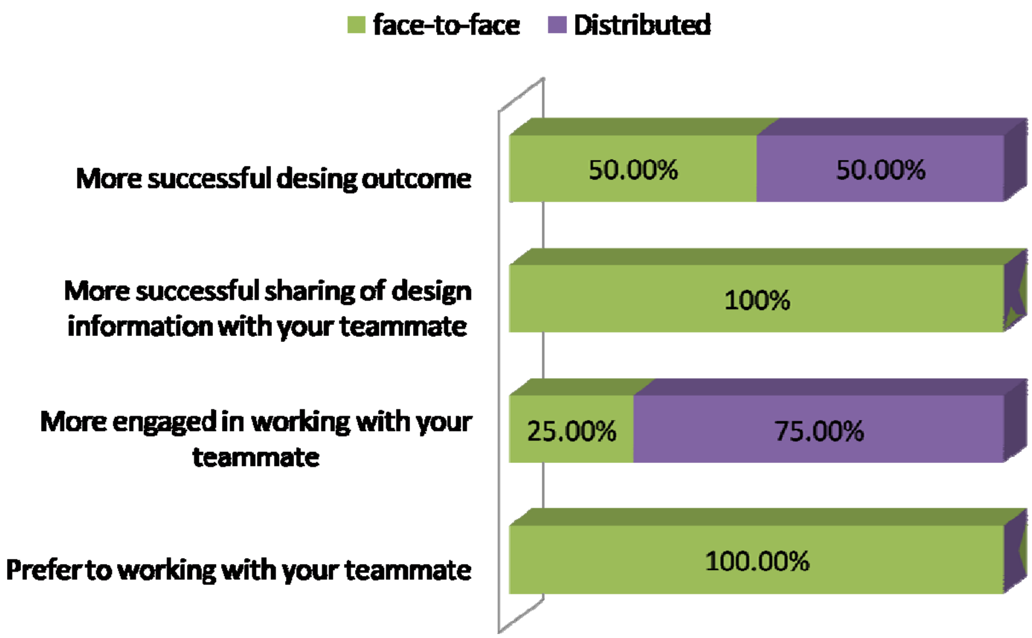


Figure 4.16 Results of Additional Questions

When asked which setting resulted in a more successful design outcome, half of participants answered face-to-face and the other half answered distributed. Participants were asked to explain why they believed one setting was better than the other. They mentioned the differences were due to the different tasks rather than the different settings.

Open-Ended Questions

At the end of the questionnaire, participants shared their opinions about the use of Unreal for the design process and the key abilities for a new collaborative system that facilitate design information sharing and interaction. Table 4.7 presents a summary of the participants' opinions about Unreal. Despite the potential impact of real-time visualization, the current Unreal engine did not sufficiently enhance design communication for the teams.

Participants stated that the Unreal virtual environment lacks communication tools and did not allow users to share ideas or manipulate objects, so they could not do much beyond viewing 3D objects together. In addition, they found it difficult to use other applications (e.g., Skype) in conjunction with the Unreal virtual environment because the latter took up the entire monitor screen.

Table 4.7 Participants' Opinions about the Unreal Virtual Environment

<table>
<tr><th colspan="2">Unreal</th></tr>
<tr><td colspan="2"></td></tr>
<tr><th>Positive Comments</th><th>Negative Comments</th></tr>
<tr><td>• Laser pointer was helpful in conveying what they were referring to on the model
• Liked multiple people sitting around a model in a virtual environment
• Easy to talk about model
• Great for visualization
• Real-time visualization</td><td>• Difficulty using Skype video with Unreal because it takes up the whole screen
• Laser pointer was less effective than just pointing to the actual screen
• Lack of communication tools such as shared drawing
• Lack of sharing thoughts and ideas
• Lack of manipulation</td></tr>
</table>

After finishing the design sessions, all design teams expressed their opinions about how to create a better collaborative system for designs. Table 4.8 summarizes design criteria based on the participants' opinions about what a better collaborative system might entail based on their experience in the design sessions. The concern most often cited was the lack of sharing capabilities between team members. Participants indicated that they wanted to see their teammate's screen, even in the face-to-face setting, because they believed it would lead to more effective collaborative conditions by giving them the ability to share visual information (e.g., 2D sketches on paper, 3D objects), make suggestions and review each other's work continually. Rather than drawing or modeling them separately and then sharing; they indicated their desire to see the process of their teammate's drawing. Participants also mentioned that integrating these sharing systems into the 3D virtual environment would facilitate the collaborative effort.

Table 4.8 Design Criteria of the Collaborative System

Collaborative System
Sharing
• Ability to manage time o A way to quickly record paper sketches with annotations o Real time information sharing • Ability to see teammate's screen and mouse o Sharing 2D sketches as they are drawing them o Sharing 3D object model in a shared view • A file sharing system that can auto save and keep a revision
3D Virtual Environment
• Integrated tool such as a sketching tool in the virtual environment • An integrated 3D modeler and 2D sketching tool with an audio channel and a web browser to search for precedence material • Ability to manipulate 3D objects within the environment • Ability to record conversations for later use • Holographic display of a 3D model

Discussion

Like Kvan (2000) suggested in his model of design collaboration (see Figure 2.3), the way designers divided their work derived from each designers' negotiation during the process. Members of Team A introduced each other to share their design experience in the first session, illustrated transcription is in Table 4.9, and this conversation led to divide each tasks based on their experience. Therefore, Team A's designer performed the 3D modeling task, and designer 2 did 2D graphic work in the distributed setting.

Table 4.9 Transcription of Team A in Distributes setting

Beginning of Design Process
Designer 1 "I have used max for 8 years now. I can do renderings without a problem" I have used Unreal for about 5 years.. so on the technical side, I don't have any problems there...."
Designer 2 "what I will do is like..I can put together in pdf. ..so, I will do the presentation"
Middle of Design Process
Designer 2 " I will start working on illustrator.. do you wanna modeling then?"
Designer 1 "okay..you gonna work on some illustrator?"

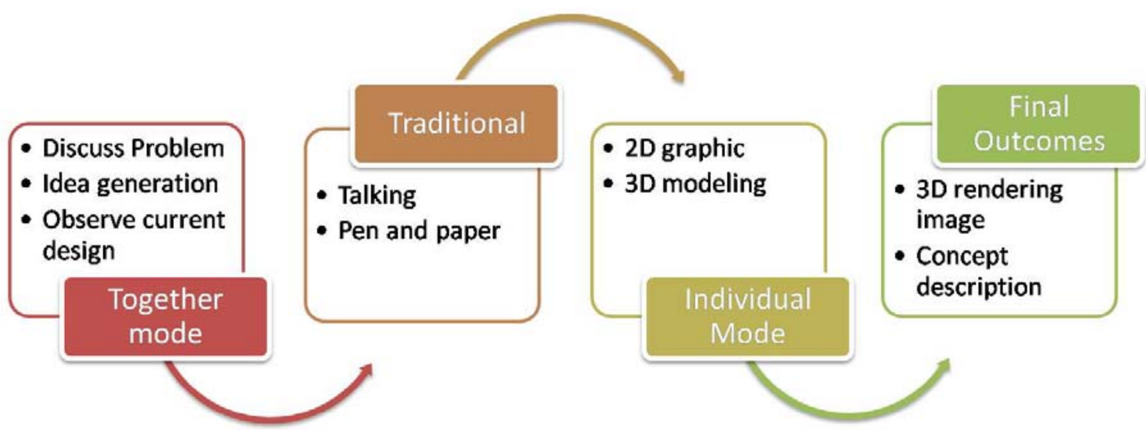


Figure 4.17 Design process in the face-to-face setting

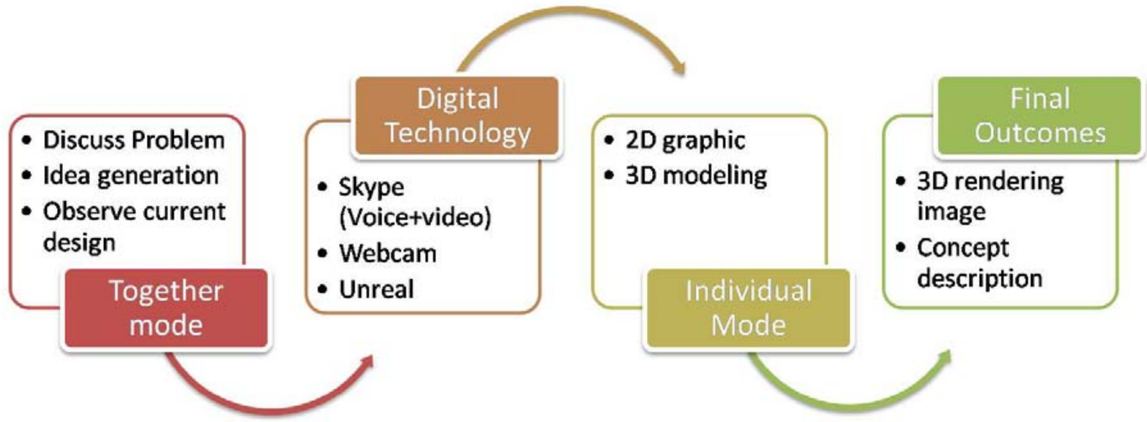


Figure 4.18 Design process in the distributed setting

Figure 4.17 illustrates the summary of the design process the teams used in the face-to-face setting; Figure 4.18 depicts the summary of the design process that teams used in the distributed setting. As the diagrams show, the only difference in the design process between the face-to-face and distributed settings were the way teammates used technologies to communicate. It is obvious that teams did not need any other technologies to communicate in the face-to-face setting except talking and pen and paper. One interesting finding was that both teams in different settings showed similar working patterns despite their use of different communication tools. They worked together until they arrived at a design concept. At that point they divided the work into the 3D modeling task and the 2D graphic task for each member to provide the final design outcomes. Moreover, both teams generated ideas more quickly in Task 2 than they did in Task 1. One explanation may be that teams had already worked together on Task 1 before working together on Task 2, so they were more knowledgeable about their teammate's strengths and weaknesses and able to start the design process faster. Another explanation could be that Task 2 was simpler to solve than Task 1, so the teams were able to produce a design in less time.

Surprisingly, as Figure 4.19 shows, teams, on average, worked together more in the distributed setting than in the face-to-face setting. In only one hour, the design teams needed to come up with a proposed design more quickly to achieve their goal. Therefore, because they could see and talk to each other in the same place, the teams were able to come up with a design more quickly in the face-to-face setting than in the distributed setting. Both teams worked together in the face-to-face setting an average of about 42 percent of the time and in the distributed setting about 55 percent. That is, teams had more time to work individually in the face-to-face setting. Thus, it appeared that the different settings were not related to the participant's perceptions of the success of their design outcomes.

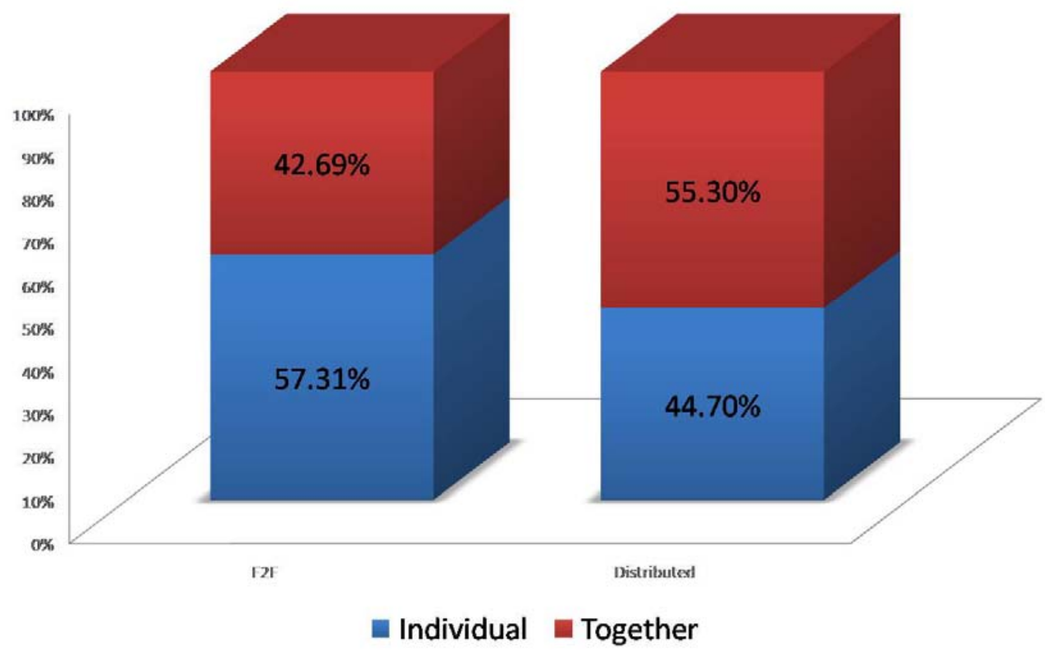


Figure 4.19 Average working mode in face-to-face and distributed settings

As was anticipated, all participants preferred working with their teammate in the face-to-face setting and indicated they believed they were more successful at sharing design information with their teammate when face-to-face because they could easily share ideas instantly and see each other's screens. This results support the claims in the literature (Lebie, et al., 1995) that participants in distributed teams exchange information less effectively than those in face-to-face teams. All the participants thought face-to-face communication was more conducive to sharing design information; and they simply preferred face-to-face to distributed communication. However, three out of four designers thought that distributed setting was more engaging to work with their teammates in. They claimed they were "forced to be engaged" and "forced to communicate better," and that they "concentrated more using hand gestures on camera."

This experiment resulted in the formulation of a number of design criteria based on the participants' opinions about how to create a better collaborative system for design teams, illustrated in Table 4.8. Among the design criteria was the lack of sharing capabilities between the team members, the concern most often cited. In other words, a system for collaborative design strongly needs a shared desktop that enables the team members to share 2D sketches or 3D object models in a shared view.

CHAPTER 5

DEVEOPMENT AND EVALUATION OF TOOLS FOR COLLABORATIVE DESIGN

This chapter describes the development and evaluation of tools for collaborative design that examined how designers in face-to-face and distributed settings collaborated through CMC technologies, and a shared virtual environment (Unreal). The methodology for both experiments was similar. However, the first study engaged two design teams using the basic CMC technologies such as Skype and CVE in both face-to-face and distributed settings whereas the second study used two different design teams and other types of CMC technologies such as Whiteboard, and shared programs for collaboration in both settings.

Evaluation Tools for Design Collaboration

The purpose of this experiment was to evaluate tools for collaborative design, so the observations focused mainly on how much time they worked together using what types of particular tools they used in both face-to-face and distributed settings. In first study, participants were frustrated by the collaborative design process because they could not shared design information effectively using the computing technology. Based on this fact, we provided different types of CMC tools, shown in Table 5.1., which allow designers to share their design information such as sketches, modeling, and observed how team collaboration increased and what types of tools actually helped them to collaborate with each other.

Communication and Design Tools

To encourage sharing between teams, we introduced Microsoft NetMeeting in this experiment, which allows the team members to sketch together using a whiteboard, application and to share any program, including 2D or 3D graphic programs, as well as video chat, or to transfer files.

Design teams were required to use CVE (Unreal) in both settings in the first experiment. In the second experiment, design teams were required to use Unreal and NetMeeting only in the distributed setting. The teams in the face-to-face setting were not required to use any of the tools. The purpose of this was to see what tools the design teams might choose to augment their collaboration.

Table 5.1 Design Session Experiment with the Provided Tools of the Second Study

Task 1 (1 hour)	**Task 2 (1 hour)**
Team C (Face-to-face) Team D (Distributed)	Team D (Face-to-face) Team C (Distributed)
Provided Tools *Required to use Unreal and NetMeeting ONLY in the distributed setting	

CMC	• Email
	• Microsoft NetMeeting
	    • Video Chat
	    • Share Program
	    • Chat
	    • Whiteboard
	    • Transfer Files

CVE	• UnrealEngine2 Runtime 2226.20.02 (Unreal)
CAD	• Autodesk® 3ds Max® 2009 32-bit (3ds Max) • Solid Works 2008 • Adobe Illustrator CS / CS2 (Illustrator) • Adobe Photoshop CS / CS2 (Photoshop)
Others	• Pen and paper • Webcam and headset

Participants

Two pairs of student design teams, different teams the first study, participated in this study. The participants are industrial design (ID) graduate students, from the College of Architecture at the Georgia Institute of Technology. All participants were male with moderate design experience. Three had a design experience for two and half years, and one had more than six years because he had ID background as undergrad, They were familiar with both CMC technologies and CAD software using those for their design projects regularly. However, none of them have used Net Meeting and CVEs in design collaboration before.

Experimental Setup

The experiment took place in the same place as the first experiment, at the CATEA Usability Lab. Same as in the first experiment, the participants could not see or talk to each other except via the CMC and the CVE technologies when in the distributed setting.

However, we provided different setting as the first experiment in face-to-face setting Whereas participants seated next to each other in with their own workspaces as were in the first experiment (see Figure 3.2), participants faced each other across the table (see Figure 5.1) in this experiment.

Figure 5.1 Face-to-face Setting in the Second Study

Procedures

Design teams were asked to perform the same tasks (illustrated Figure 3.4) as those used in the first study. They were given Task 1 on the first day and Task 2 on the second day. Each task lasted one hour. However, Team C performed Task 1 in the face-to-face setting while Team D did it in a distributed environment. Then they switched settings: design team D was in the face-to-face setting while design team C was in the distributed setting for Task 2.

In the first design workshop, each participant was given an informed consent form and video release form, which were approved by the Georgia Tech IRB. Both forms are available in Appendices B and C, respectively. Following the signing of the consent forms, a researcher demonstrated how to use the Unreal Virtual Environment (CVE), and Microsoft NetMeeting (video chat, whiteboard, shared program, and transfer files) because participants did not have any experience of using Unreal and Microsoft NetMeeting. Then, participants had time to practice to make sure they can use those tools for the tasks. The introduction sheet for Unreal, which introduces basic usage such as mouse control was provided (see Appendix J). After the participants indicated that they were comfortable using the technologies available, they were given an instruction sheet (Appendices F and G) describing the design problem and requirements.

Design teams had one hour to complete each task, and they submitted a 16"x16" poster(pdf format) of their final outcomes like other design teams did in the first study. After finishing the design task, the participants were given a questionnaire (see Appendix H) that asked them to state their level of satisfaction, their expectations of collaborative work in face-to-face and distributed situations, the benefits they foresaw for the design process, and concerns they had about the communication tools. In the second session, they were asked to compare both design settings in additional questionnaires (see Appendix I).

Measures

The study focused on how much time teams worked together compared to the first study and what types of tools helped them collaborated. Thus, the measures used were based on Kvan’s definition (Kvan, 2000) of collaborative design as a "closely coupled" or "loosely coupled" process. In this study, the "together" state measured the amount of time designers communicated and shared design information about their design, and “individual" refers to the amount of time designers worked on tasks individually. Using these two measures, shown in Table 5.2, researchers also looked at five different communication modalities for each design process: talking, gesturing, writing, sketching, and modeling. The measuring of minutes in collaboration was substantiated to study how much design the teams increased their collaboration time as compared to the first study. In addition, researchers determined when and what types of the CMC tools (i.e., video chat, IM, whiteboard, shared program design) the teams used and verified what types of technologies the teams chose to use for collaboration in working "together".

Instead of evaluating design team's final outcomes, as was done in the first experiment, researchers evaluated the team effectiveness for successful collaboration. The evaluative techniques were adopted from Sbea and Guzzo, who proposed three ways to measure the success of group effectiveness: task interdependence (how closely group members work together), outcome interdependence (whether and how group performance is rewarded), and potency (members' beliefs that the group can be effective) (Sbea & Guzzo, 1987)

Table 5.2 Coding Scheme for the Second Study

<table>
<tr><th colspan="2">WHO</th></tr>
<tr><td>Face-to-Face
Team C/Team D</td><td>Distributed
Team C/Team D</td></tr>
<tr><th colspan="2">WORKING MODE FOR COLLABORATION</th></tr>
<tr><td></td><td>Minutes in Collaboration</td></tr>
<tr><td>Together
Individual</td><td>Meeting and sharing the proposed design
Working individually on the proposed design</td></tr>
<tr><th colspan="2">TOOLS FOR COLLABORATION</th></tr>
<tr><td>Communication Modalities</td><td>Types of Communication Tools</td></tr>
<tr><td>Talking
Gesturing
Writing
Sketching
Modeling</td><td>Video Chat
Chat
Shared Program
Whiteboard
Unreal (CVE)</td></tr>
</table>

Data Coding

The data from the two design workshops included four continuous streams of video and audio data. The stream of data for each workshop was segmented for coding using Observer XT 8.0 software like what was used in the first study. However, this study focused on working mode and tools for collaboration based on coding scheme, as shown in Table 5.2. After coding each video of collaborative design process, Observer XT 8.0 software provided integrated visualization data showing what the two participants were doing and what communication modalities and tools when they were collaborating over the course of the design workshop. Then, each coding scheme was color coded, as shown Figure 5.2, by a researcher to visualize the design process diagram (Figures 5.3 and 5.4). The communication modalities includes the modes of talking, gesturing, writing, sketching, modeling and working. The CMC includes video chat, chat, shared program, and shared white board from NetMeeting, and the CVE is used the Unreal.

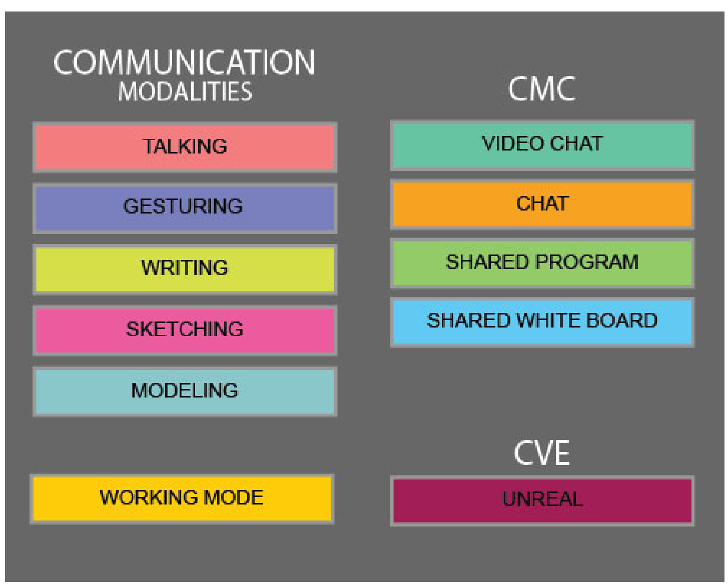


Figure 5.2 Color-Coded Coding Scheme

Results

We found interesting results from the design sessions of these two teams. Two teams provided results of collaborative design in face-to-face, and distributed setting. Eventually, we could compare of findings from the second study to the first study that how much teams worked "together" more and what types of tools helped their collaboration.

Collaborative Design in a Face-to-face Setting

The purpose for observing collaborative design in a face-to-face setting was to determine the strength of the effectiveness of collaborative design. Team C performed Task 1, and Team D Task 2 in the face-to-face setting, illustrated in Figure 5.3 (see Appendix U for a larger diagram). Both teams exhibited a similar number of communication modalities. Teams engaged in "talking" in most parts of the task (Team C: 46 percent of the total time; Team D: 47 percent), and CAD tools (Team C: 36 percent of the total; Team D: 31 percent of the total). Both teams used "sketching" about 20 percent of the total time. Neither team used Unreal as a design tool for this setting. When teams talked or showed sketches, "gestures" played a large role in their design communication, and they used "writing" when they annotated and described their design ideas on the presentation board. In addition, only Team C used the shared program when they worked on their 3D model face-to-face, but Team D did not use any of the CMC technologies in this setting.

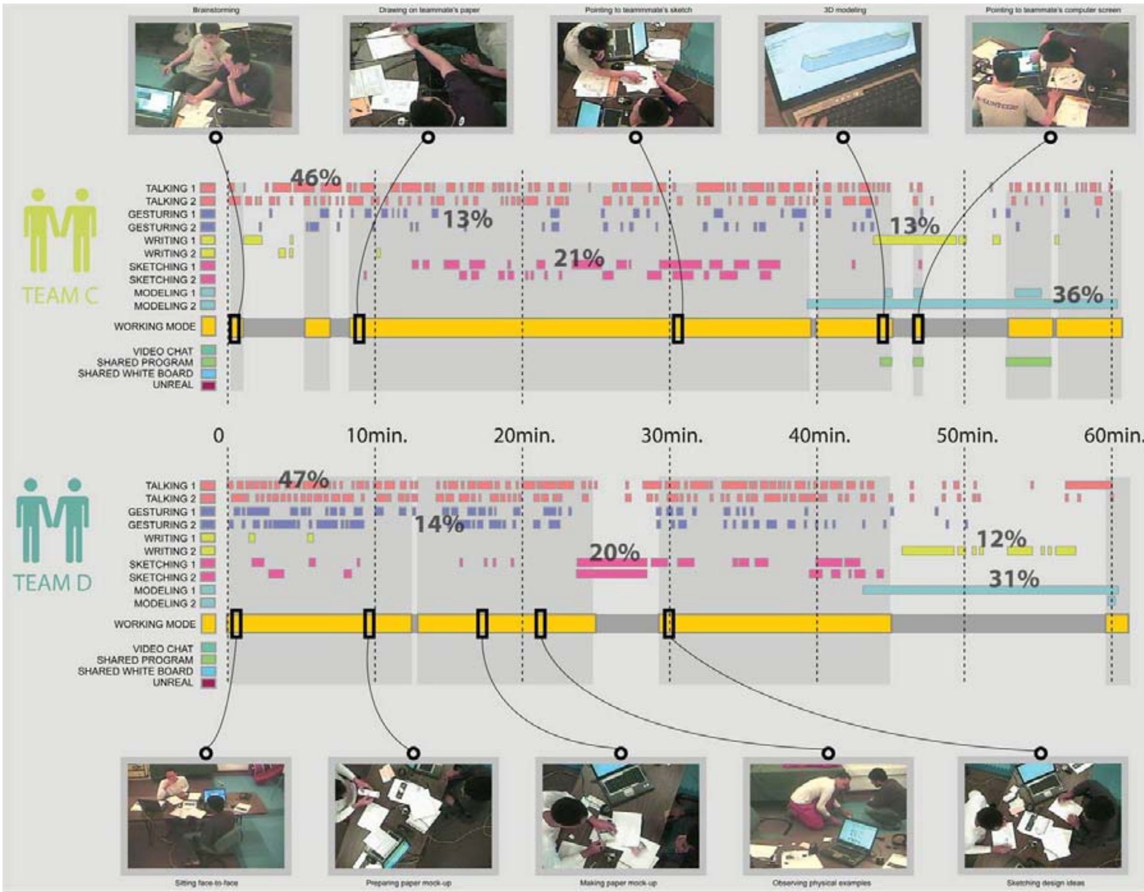


Figure 5.3 The Teams' Design Process in the Face-to-Face Setting

Collaborative Design in a Distributed Setting

Unlike in the face-to-face setting, both teams used a variety of CMC technologies in the distributed setting. Team C performed Task 2, and Team D Task 1 in the distributed setting, illustrated in Figure 5.4 (see Appendix V for a larger diagram). Both teams spent most of their time on 3D modeling, and they used less talking, gesturing, and sketching, than they did in the face-to-face setting. On average, teams used talking (47 percent of the total), gesturing (14 percent of the total), and sketching (21 percent of the total) in face-to-face, whereas they used talking (35percent of the total), gesturing (4 percent of the total), and sketching (11 percent of the total) in distributed. However, they more frequently used the NetMeeting program to collaborate on the 3D model, the whiteboard to sketch together, and video chat to see and talk to each other than they did in the face-to-face setting.

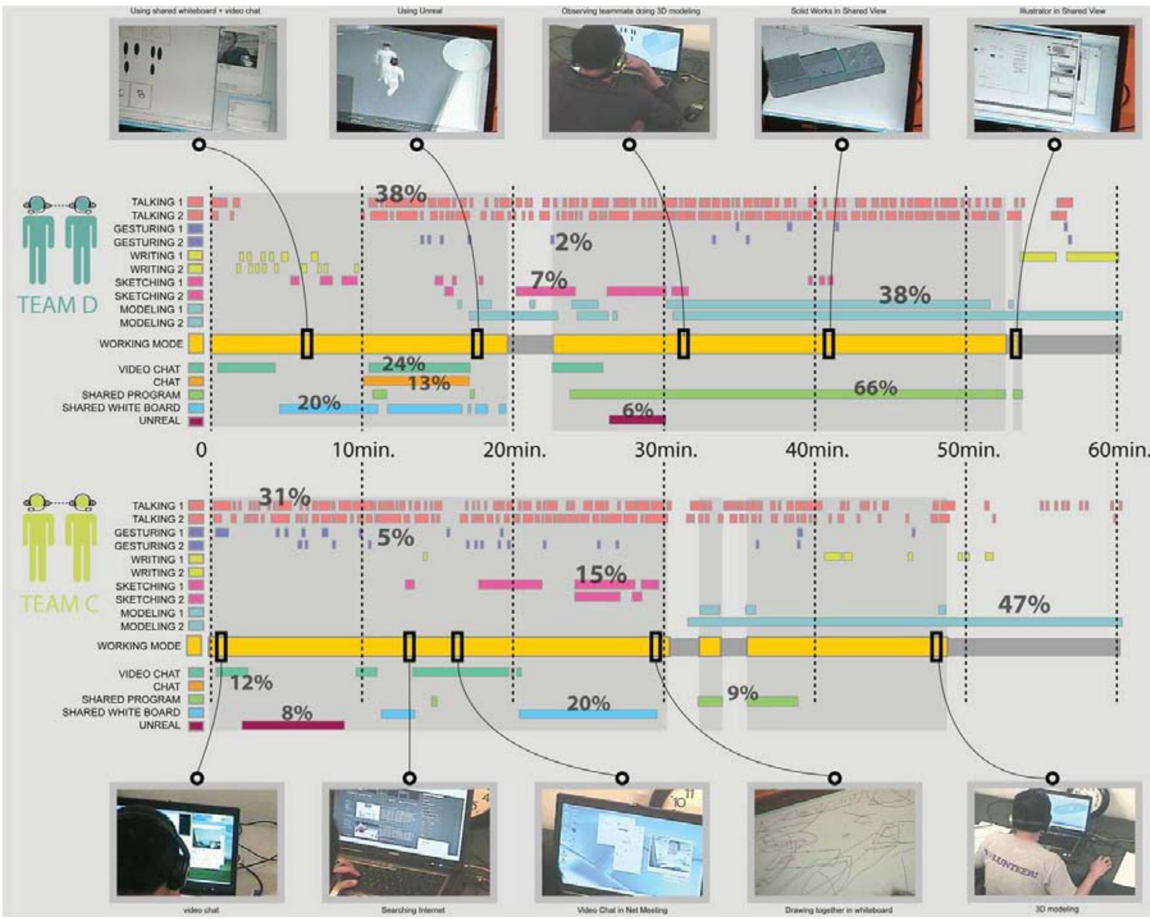


Figure 5.4 The Teams' Design Process in the Distributed Setting

Teams used modeling in most parts of the task (Team C: 47 percent of the total; Team D: 38 percent of the total), and talking (Team C: 31 percent of the total; Team D: 38 percent of the total). Both teams used Unreal (Team C: 8 percent of the total; Team D: 6 percent of the total). Both teams rarely used gesturing in this setting (Team C: 5 percent of the total; Team D: 2 percent of the total). Team D used a sharing program for most of the task (66 percent of the total time). While one designer was modeling in Solid Works, another designer was able to see the 3D object in a shared view at the same time to discuss some details of th0e design collaboratively.

Tools in Collaborative Design

The use of tools in the collaborative design process in the face-to-face setting differed significantly from that in the distributed setting. While face-to-face, design teams were able to share physical objects such as paper mock-ups, sketches on one piece of paper, and even the computer screen. Figure 5.5 shows the design team sketching together on the same, shared piece of paper, and Figure 5.6 shows one team member pointing to his teammate's computer screen.

Figure 5.5 Team C Sketching on the Same Piece of Paper

Figure 5.6 Team C Sharing Digital Information With One Team Member Pointing at the Computer Screen

Team D often moved out of the work space, for example, when they were looking for paper mockup materials in the room. The team members were creating a paper mockup together, as illustrated in Figure 5.7., and observing a real extension cord for their research, as illustrated in Figure 5.8.

Figure 5.7 Team D Engaged in Creating a Physical Mock-up

Figure 5.8 Team D Observing a Real Extension Cord

While distributed, design teams were able to share design information such as sketching together and viewing 3D objects together using the Microsoft NetMeeting shared program (Figures 5.9 and 5.10). While one designer was modeling in Solid Works, the other was able to view the 3D object in a shared view (as shown in Figure 5.11) at the same time, so they were able to discuss some details of the design collaboratively, illustrated in Figure 5.12. Among the provided tools in distributed, the shared program and the whiteboard were used the most by Team D and Team C, respectively, as illustrated in Figure 5.13.

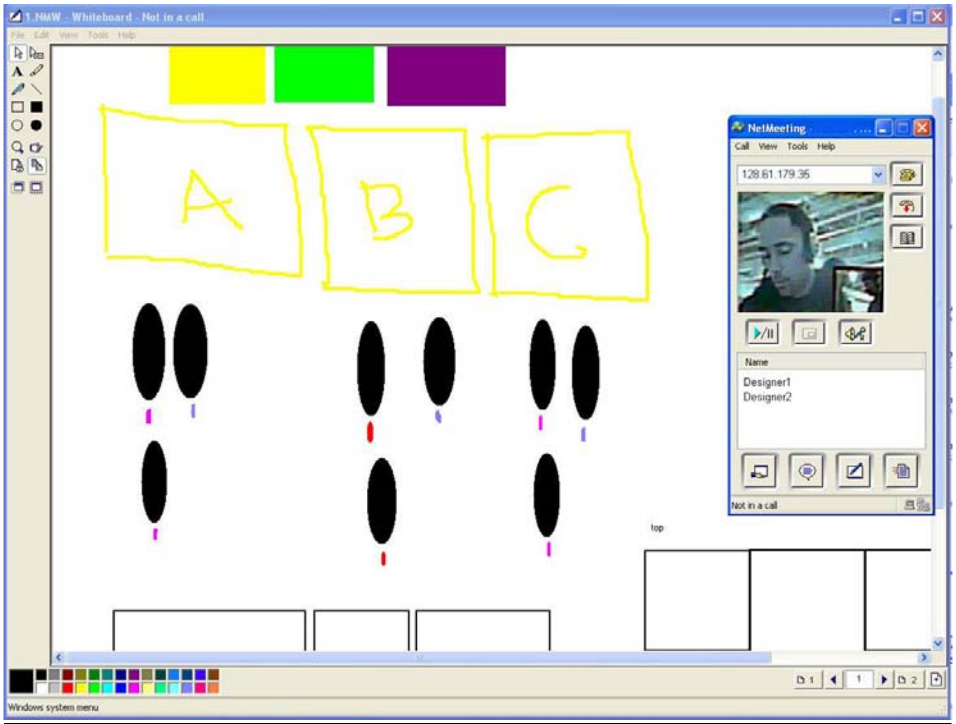


Figure 5.9 Team D Video Chatting and Sketching Together Using a Whiteboard

Figure 5.10 Designers Observing His Teammate's 3D Modeling Using the Shared Program

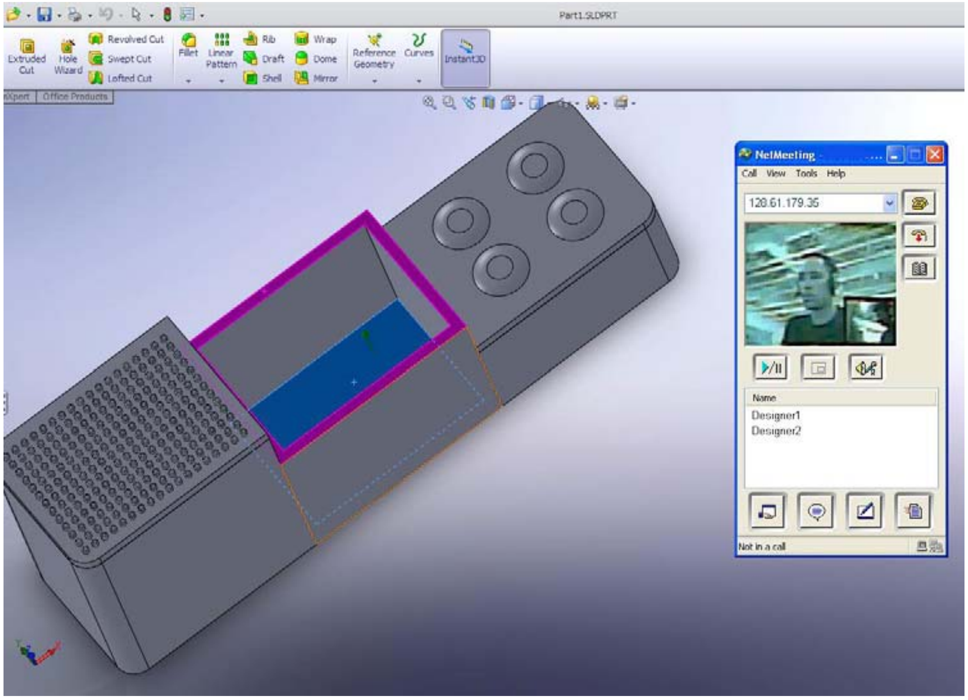


Figure 5.11NetMeeting Sharing 3D CAD Program with Video Call

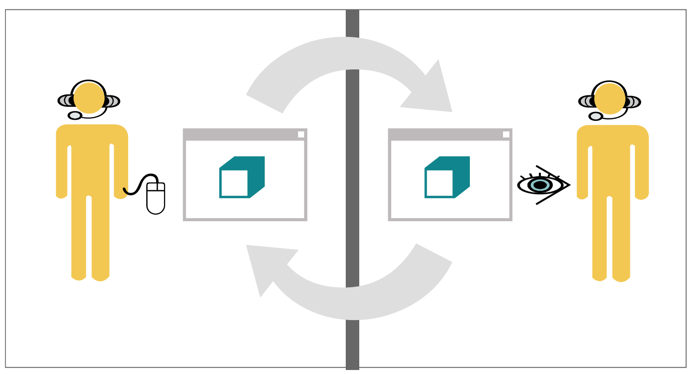


Figure 5.12 Team Sharing 3D Object (One is Modeling and One is Viewing)

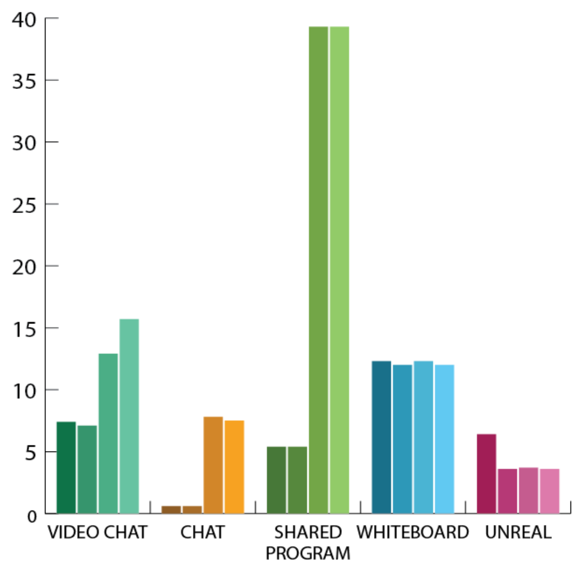


Figure 5.13 Minutes of CMC Used in Collaboration

Communication Modalities and Types of Tools

Another main variable was the type of communication modality - talking, gesturing, writing, sketching, and modeling. In addition, the study observed what features of tools were used with each of the communication modalities.

In the face-to-face setting, one representative traditional tool, pen and paper, was used with three communication modalities—writing, sketching, and modeling. However, various tools were linked to all the communication modalities in the distributed setting, illustrated in Figure 5.14. Specifically, video chat was used for talking and gesturing, shared program was mainly used for modeling, and shared whiteboard was used mainly for sketching together.

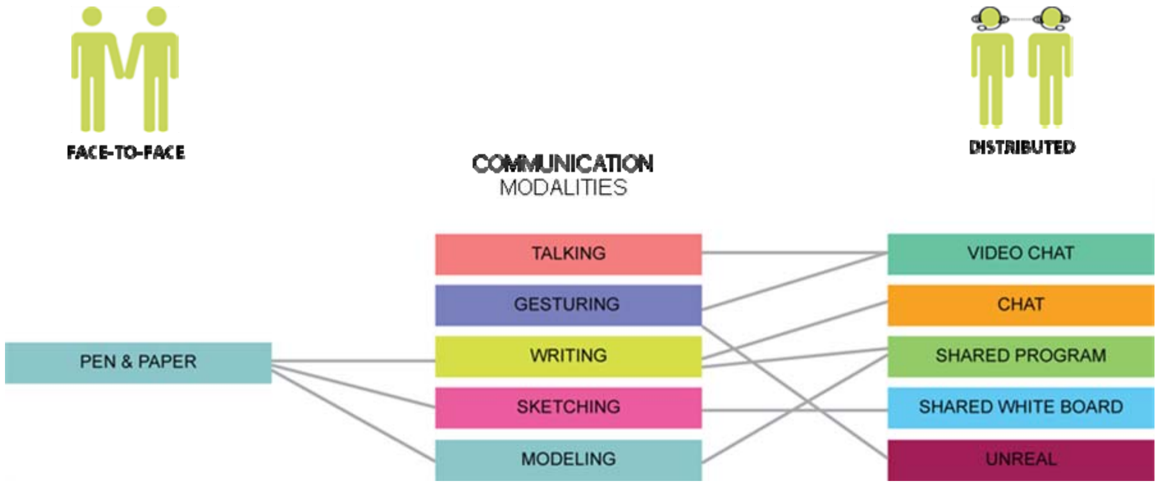


Figure 5.14 Communication Modalities with Tools in Face-to-Face and Distributed Settings

Questionnaires

Post-questionnaires revealed that the participants were satisfied with the shared program, chat, whiteboard, and transfer files, as they were able to conduct multiple tasks at the same time between two people for easy collaboration. They also rated the effectiveness of CMC 8-9 out of a possible 10. As a result, the shared program and the whiteboard function from NetMeeting helped the design teams to share real time information. Team participants commented that this program facilitated the collaborative process by enabling both to perform multiple tasks such as talking with their teammates and observing 3D object in a shared view at the same time.

Questionnaires in a Face-to-face Setting

The results of the self-evaluation of the participants in the face-to-face setting showed most received high evaluation scores (8-9) in terms of overall interactions of the team, the quality of product, and the use of communication tools.

Obviously, teams did not use most of CMC and CVE in face-to-face, but they used Email, Share Program, or Transfer files when they had to share their 3D file. Not surprisingly, the most frequently used tools in this setting were pen and paper. Both teams used these as a sketch tool, and team C tried to make a paper mockup.

Questionnaires in a Distributed Setting

The results of the self-evaluation of the participants in the distributed setting also showed most received high evaluation scores (8-9) in terms of overall interactions of the team, the quality of product, and the use of communication tools. Of those, teams rated high evaluation scores (9-10) as a design communication tool in the distributed setting.

Teams were satisfied of using NetMeeting in terms of sharing design information (rated 8-9). Participants said "it really helped to be able to have multiple tasks happening at once between two people", "the chat and Whiteboard really made collaboration easy. We shared the Solid works and the illustrator programs"

Questionnaires of Comparison between face-to-face and Distributed Setting

After the second design session, participants were asked to compare working in the two settings as teams did in the first study. The provided question sheet is in Appendix H. The participants were asked to explain why they believed one setting was better than the other. All the participants thought face-to-face communication was more conducive to sharing design information; and they simply preferred face-to-face to distributed communication. They differentiated face-to-face as tangible design process verses distributed as digital design process. “The face-to-face sharing seemed to be more tangible whereas the distributed was all digital" "Ability to create mock-ups together. The result more tangible" "We can simulate scenarios and create mock-ups in real time." Participants liked being together at the same physical place. In addition, participants thought face-to-face communication was more conducive to sharing design information. They said "easier to share via paper sketches and pointing and gesturing"

Like the first study showed, participants also thought they were more engaged with their teammate in distributed than in face-to-face setting in this study. "The virtual environment increased my concentration level, which helped me engage better" "forced to be engaged because otherwise there is zero communication"

One participant preferred to working in distributed than in face-to-face in the future. He said, "The distributed way of working is the future and will allow for designers to work independently on a group project. I would prefer leaning this rather than continuing the old way of designing (I can work from home with my dog)"

Comparison of Findings from Experiment 2 to Experiment 1

To evaluate the tools used in the second study based on the design criteria from the first experiment, we compared the working mode (i.e., together or individual) by time in both experiments. Yellow bar shows the working together time and grey bar shows individual working mode in each collaborated design process, illustrated in Figure 5.15.

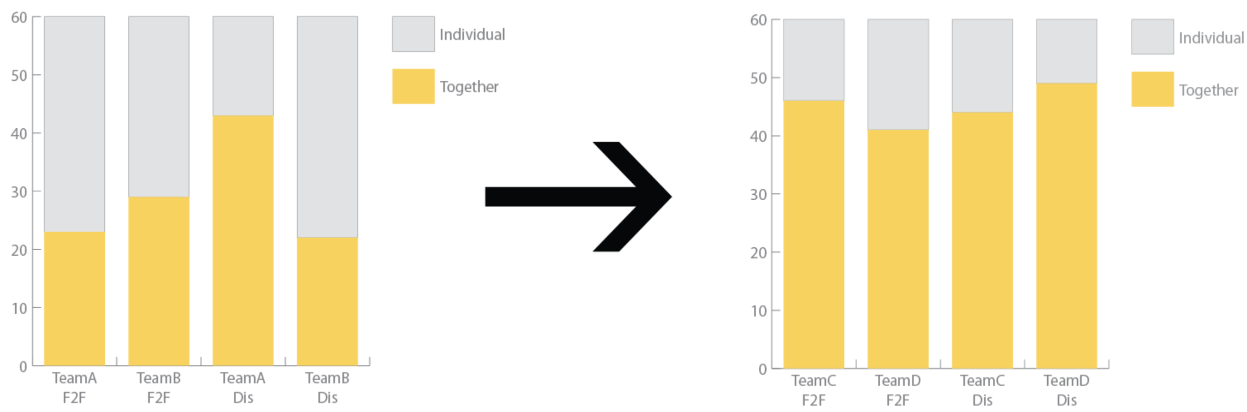


Figure 5.15 A Comparison of the "Working Modes" of the experiments, the first (left) and the second (right)

All the design teams, whether in face-to-face or distributed settings, worked together on all tasks for more than 40 minutes in the second experiment while they worked together on only one task for more than 40 minutes in the first, illustrated in Figure 5.16.

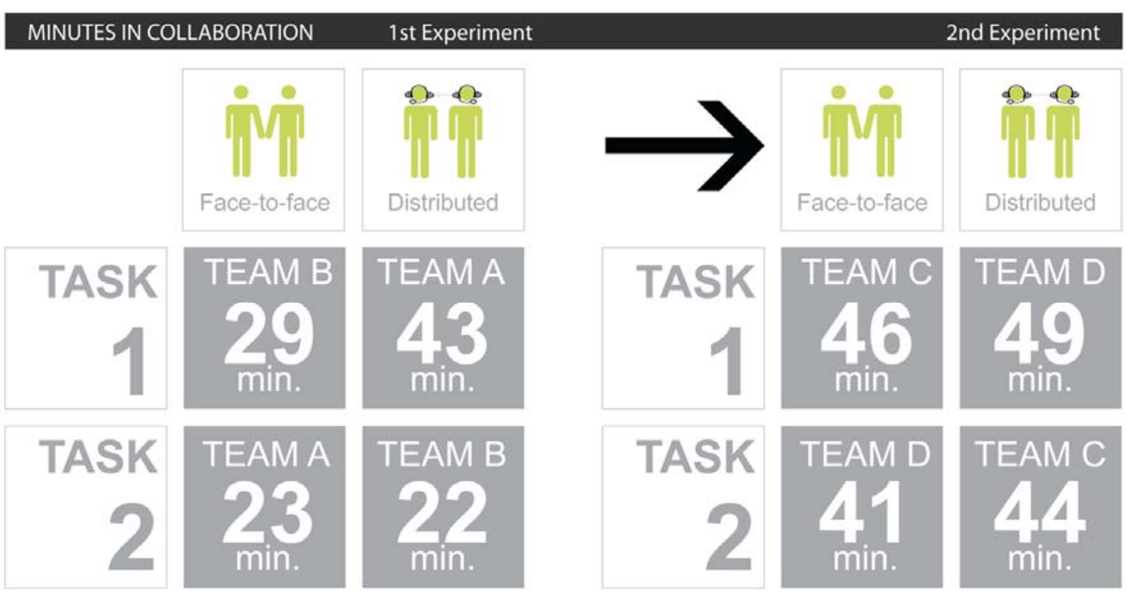


Figure 5.16 "Working Modes" Comparison of First Experiment (left) and the Second Experiment (right)

During the first one-hour experiment in the face-to-face setting, both Teams A and B worked together only 23 and 29 minutes, respectively, but Teams C and D worked together 46 and 41 minutes, respectively, representing an average increase of 17.5 minutes (29.2 percent of the overall time). In the same experiment in the distributed setting, Teams A and B worked together 43 and 22 minutes, respectively, while in the second experiment, teams C and D worked together 49 and 44 minutes, respectively, representing an average increase of 14 minutes (23.3 percent of the overall time). On average, teams worked together 29 (48.3 % of the overall time) and 45 minutes (75% of the overall time) in the first and second experiment, respectively. In other words, the teams in the second experiment worked longer together than they did in the first experiment.

In addition, the teams worked together six minutes longer in the distributed setting than in the face-to-face setting. As they were able to see and talk to each other in the face-to-face setting, they were able to formulate a design more quickly than in the distributed setting. Both teams in second experiment expressed that it was easy to collaborate using NetMeeting software.

Discussion

The First Study

In first study, design teams in both settings exhibited a similar pattern in collaboration strategy. They worked together on average less than 50% of the overall work time, illustrated in Figure 5.17. In this figure, yellow bar shows the “working together” time, and grey bar shows the “working individually” time. In the first study, the design teams worked individually after dividing the work until the end because they did not have the tools that enabled them to share their design information easily.

In fact, participants were frustrated in the distributed setting because they could NOT share design information effectively using the computing technology tools on the collaborative design process. As a result, first study provided a number of design criteria that was used to develop and test an enhanced communication system that supports interaction and information sharing in distributed settings (discussion later in CHAPTER 6). These design criteria included the ability to share real time information such as sketches, 3D models, and integrated visualization tools in the 3D virtual environment.

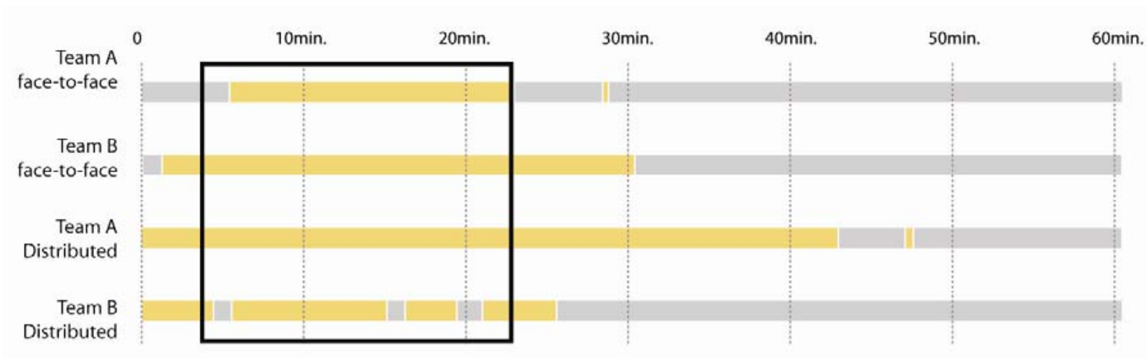


Figure 5.17 Collaborative Design Process in the First Study

The Second Study

The second study shows that teams spent more time working together when using programs that support shared sketching abilities or shared viewing of 3D objects. In addition, they showed different pattern in collaboration strategy than first study. Design teams worked together not only longer but also more broaden than first study, as illustrated in Figure 5.18.

Unlike in the first study, the teams were able to work together after they divided the work using the shared program. As shown in Figure 5.18, the teams sketched together using the digital whiteboard function and shared 3D objects using the

NetMeeting program. Therefore, the study shows that these features of tools facilitated the collaboration of the design teams even when they were working on different tasks.

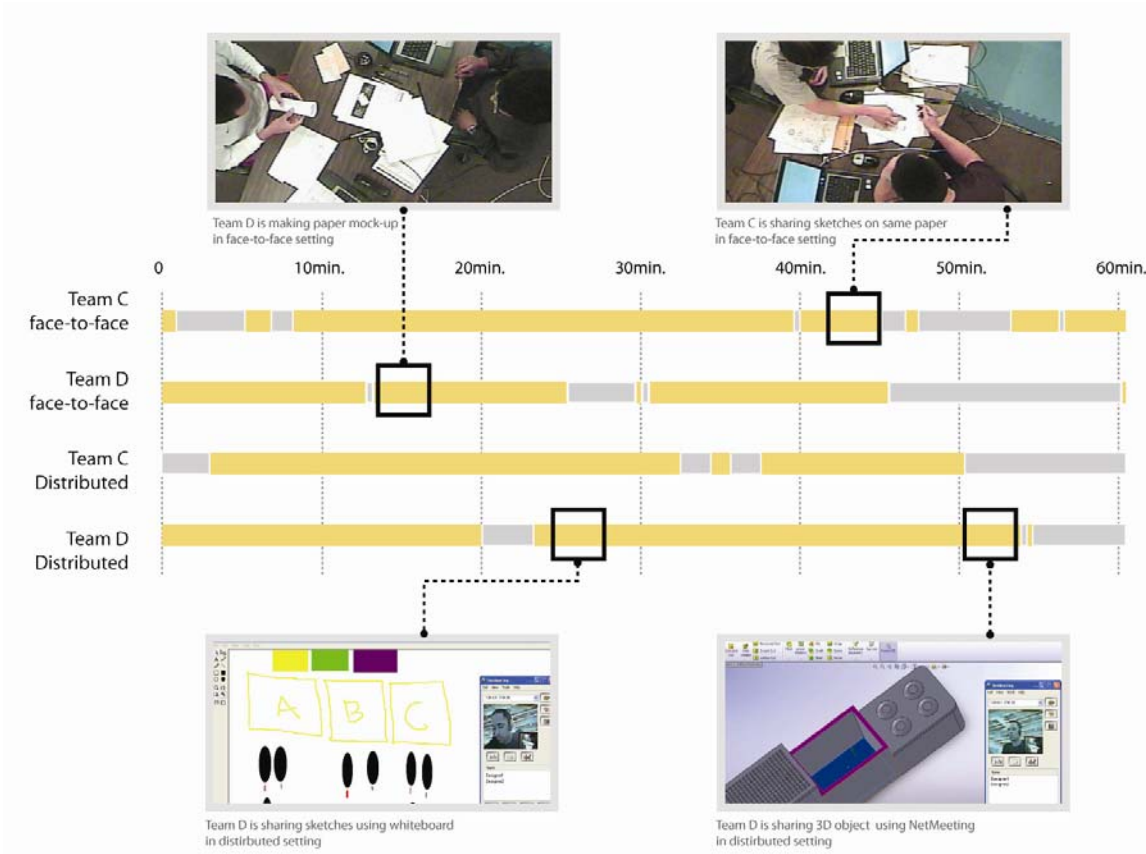


Figure 5.18 Collaborative Design Process in the Second Study

Face-to-face Vs. Distributed Collaboration

The study investigated how the face-to-face and distributed design processes differed. Figure 5.19 shows that the teams in the face-to-face setting experienced a more tangible design process such as sharing physical examples in the same place. Design team members described that "The face-to-face sharing seemed to be more tangible whereas the distributed was all digital" in the questionnaires. Design teams in the face-to-face setting were able to share tangible objects and instant communication because they were in same place and because they did not have to use technologies. In contrast, design teams in the distributed setting were not able to share tangible objects because they were in different places.

The most significant factor for collaboration in the face-to-face setting was the ability to manipulate the same physical object and access shared information without technology. However, in the distributed setting, teams can share only virtual space. Thus, distributed team members must use technologies to communicate with each other. Due to the effectiveness of the technologies, teams reported increased concentration and engagement in the distributed setting, but not in the face-to-face setting.

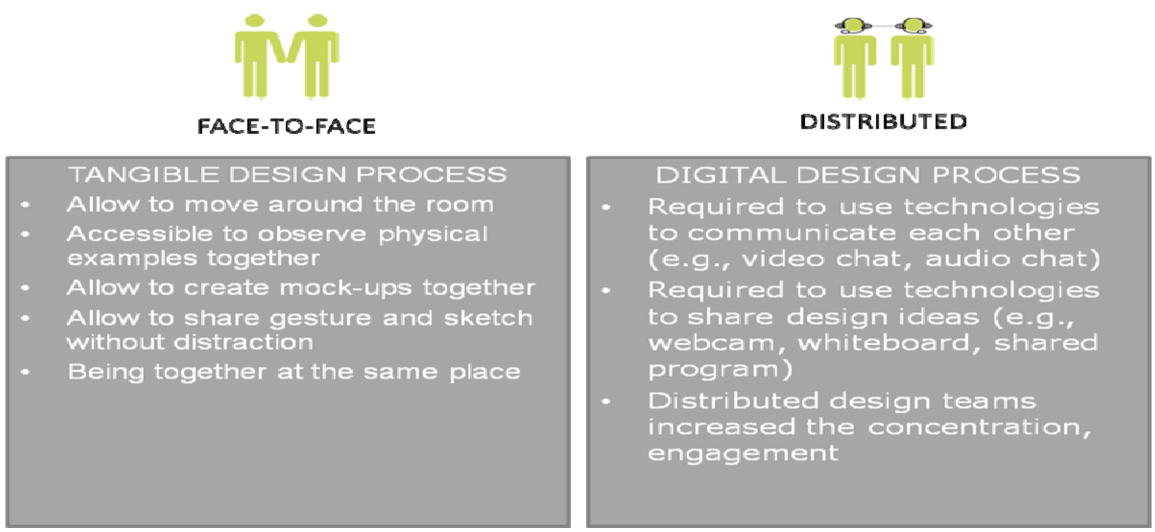


Figure 5.19 Comparison of face-to-face (left) and distributed (right) team design process

Effective Tools for Collaboration

From the two studies, we were also able to verify the effectiveness of the current CMC and CVE for collaborative design. Table 5.3 shows how the design teams regarded the use of tools during their design process. Among the CMC technologies, the shared program and video chat were the most effective tools because they allowed them to view and discuss the design information, such as the 3D object, in person.

Table 5.3 Effectiveness of Design Tools for Collaborative Design

Communication Modalities	F2F	CMC							CVE
		Email	Audio Chat	Video Chat	Instant Messenger	Shared Whiteboard	Shared Program	File Transfer	Unreal
Talking	●	○	●	●	○	○	○	○	○
Gesture	●	○	○	●	○	○	○	○	◖
Writing	●	●	○	○	◖	◖	◖	◖	○
Sketching	●	○	○	◖	○	●	●	◖	○
Modeling	●	○	○	◖	○	○	●	◖	○

● **Addressed** ◖ **Addressed to an Extent** ○ **Not Addressed**

CHAPTER 6

DISCUSSION AND CONCLUSION

Discussion

This chapter describes the findings, an interpretation of the studies, and a recommendation of a system for distributed design collaboration that supports interaction and information sharing. Despite the small number of design teams, the two studies of collaborative design supplied abundant information that are very helpful. All the design teams reached a relatively successful outcome. After the workshop session, they reported that they were reasonably satisfied with their design outcomes, the process, and communication with their teammates, and they admitted that they had fun in the sessions. However, the process of collaboration and the use of communication tools in the two studies differed significantly. The main goal of the study was to develop recommendations for a system that more effectively supports design communication, designer interaction, and information sharing. We were specifically interested in the research finding in the following three categories:

1. A comparison of face-to-face and distributed design collaboration.

2. Types of computer-supported tools that facilitate communication and collaboration in a distributed environment.

3. The impact of the 3D virtual environment on design collaboration

Studies have shown considerable differences between face-to-face and distributed collaborative design process. In the face-to-face setting, teams showed a more tangible design process. For example, they were able to move around the room, access and observe physical examples, and create physical mock-ups together. Post-test questionnaires revealed that the participants greatly enjoyed the tangible experience, specifically crafting mock-ups together and moving around the room for inspiration. In other words, they felt that face-to-face collaboration was more effective and more dynamic and that they experience more of a human connection than they did in distributed collaboration. Evidence of their experience is supported by the experiments in which the design teams were gesturing and sketching about fifty percent more in the face-to-face setting than in the distributed setting. In addition, they talked more face-to-face as tangible interaction facilitates communication. Designers might not enjoy drawing on digital Whiteboard, so they prefer sketching on physical paper. One interesting contrast between the first study and the second study was that the increase in the amount of time that the teams worked together face-to-face in the second study. Even though the teams used almost the same traditional tools such as pens and paper in both studies, they worked considerably more time (an average of 17.5minutes) in the second study than those did in the first study. That is, the different setting might have been more conducive to their working together. Instead of sitting at a different desk next to one another (as shown in Figure 3.2), they sat at the same desk facing each other (as shown in Figure 5.1), which allowed them to work more together with tangible interaction.
Understanding the strength of face-to-face collaboration could lead to the development of a better collaborative system for distributed design teams. To bridge the gap between

face-to-face and distributed settings, designers would require more tangible interaction with computer-supported tools even while they are in a distributed environment.

In contrast to face-to-face teams who are able to manipulate the same physical object and access the same physical, shared information without technology, distributed teams can share only virtual space with technology. Thus, it is important to identify the technologies that facilitate more collaboration between distributed team members. The first study has shown that CMC tools such as video chat using headsets and a webcam allow designers to see, talk, and even share sketches through the webcam. Post-test questionnaires submitted by the participants showed that they considered CMC tools such as NetMeeting and Whiteboard really helped both team members to conduct multiple tasks at the same time beyond the technical difficulties. Specifically, they felt that chat and whiteboard made their collaboration easy because they provided real-time interaction. Both chat and shared whiteboard allow real-time communication and spontaneous interaction, allowing designers to interact more with each other. Even though they had the same real-time interaction, chat was text-based and the whiteboard was visually based. Both writing and sketching were important factors when designers were sharing ideas. In addition, NetMeeting Shared program helped them to share 3D models so that they were able to see their teammates' screen on their own screen, permitting them to make suggestions and review each other’s work continuously.

The studies also revealed the impact of the 3D virtual environment on design collaboration. One of the strengths of current Unreal was that the team could convey ideas about the model in using a laser pointer in the 3D virtual environment. Findings from the studies revealed that designers have used gestures to show either sketches or 3D models rather than to describe the ideas through verbal communication. They often noted that, when sharing ideas, team members used the phrase "like this" when referring to physical (e.g., a sketch or an actual model with fingers) or digital (e.g., a sketch with a mouse) information. The gesturing of visual information by a designer is unique and one of the most important aspects of the new system. Therefore, with instant visual information in 3D, distributed design teams would have a powerful resource in the new system. Although current CVE (Unreal) did not lead to effective collaboration, several potential features such as creating virtual mock-ups for the brainstorming within a virtual environment were introduced. Participants consider real time 3D visualization effective in the design process and thus very promising in the collaborative setting if they can share ideas easily within a 3D virtual environment. Specifically, they not only want to share a 3D object model, but they also want to be able to manipulate it simultaneously in a shared view.

Recommendations for a Collaborative System

Even though the results showed that the CVE lacked sufficient communication capabilities for distributed teams, researchers believe that CVE can potentially improve collaboration. Therefore, in a distributed setting, this study recommends a collaborative system that supports interaction and information sharing based on the findings from the two studies. Figure 6.1 describes key features of computer-supported tools (e.g., CMC and CVE) that would be appropriate for such a system, illustrated in Figure 6.2. If a system has all the features such as VoIP , it would easily be able to support both the interactions and the design information sharing of designers instead of running multiple computer-supported tools.

We suggest that a built-in, multi-shared workspace such as documents and 2D, 3D files will allow teams of designers to share real time design information so that they can collaborate effectively even when they are distributed. A built-in VoIP will allow ease of communicate without distractions within a virtual environment. For example, if teams share a whiteboard for sketching within this shared system, they can sketch together online while looking and talking to each other through VoIP, as shown in Figure 6.3.

More importantly, the capability of sharing physical sketches using an overhead projector would allow tangible interaction that used to take place only face-to-face within the virtual environment. Even if the teams sketch on their own physical paper while they are in distributed setting, they could share instantly within this system by scanning from an overhead projector, illustrated in Figures 6.4 and 6.5. This feature bridges the gap between the use of physical and digital tools for sketching. This unique feature could render such collaboration as effective as face-to-face collaboration.

The capability of importing a 3D model and manipulating 3D modeling together within a virtual environment would be an important feature for design collaboration, and it will enhance synchronized interaction when designers share 3D visual ideas. Instead of sharing 3D CAD files through emails, teams would share 3D files in a shared space at the same time, illustrated in Figure 6.6. Furthermore, if teams can manipulate their 3D files at the same time, this system for collaboration would be more dynamic and effective than any other existing tools.

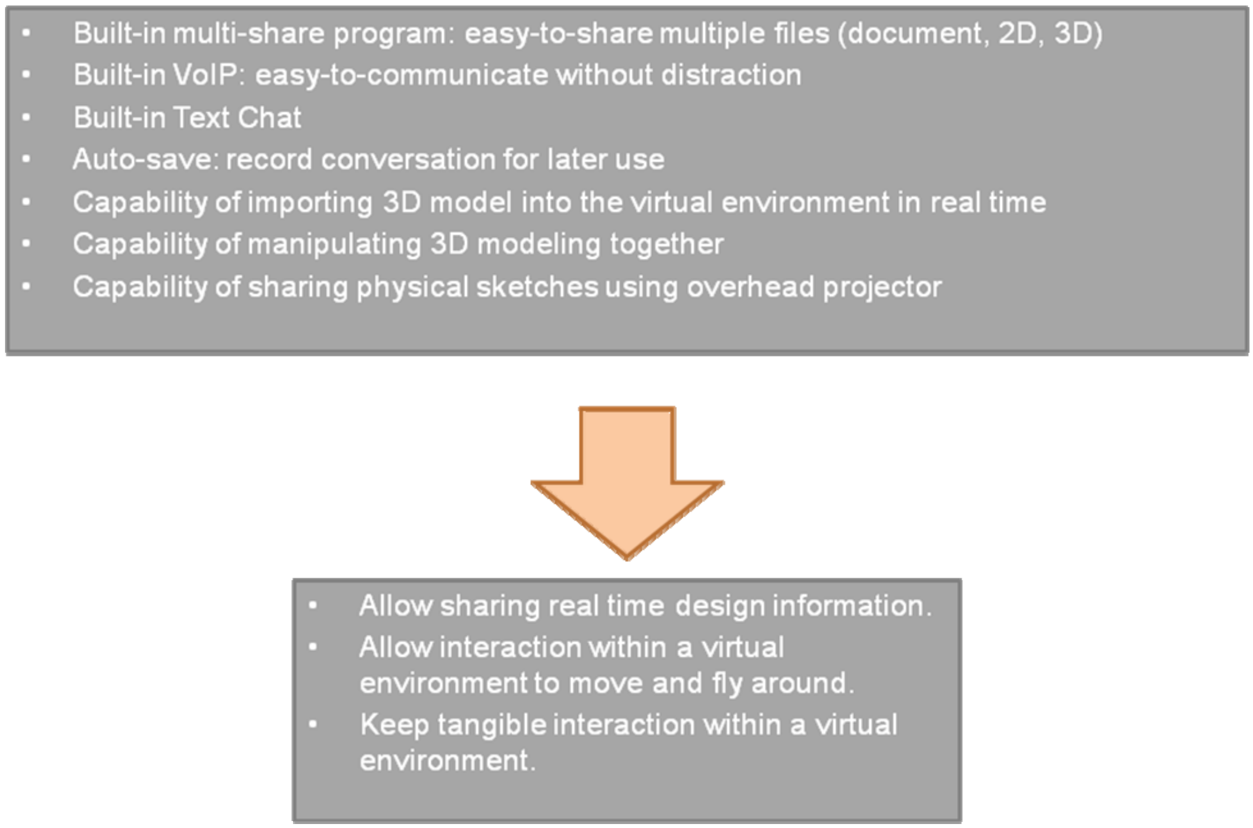


Figure 6.1 Recommendations for a Collaborative System

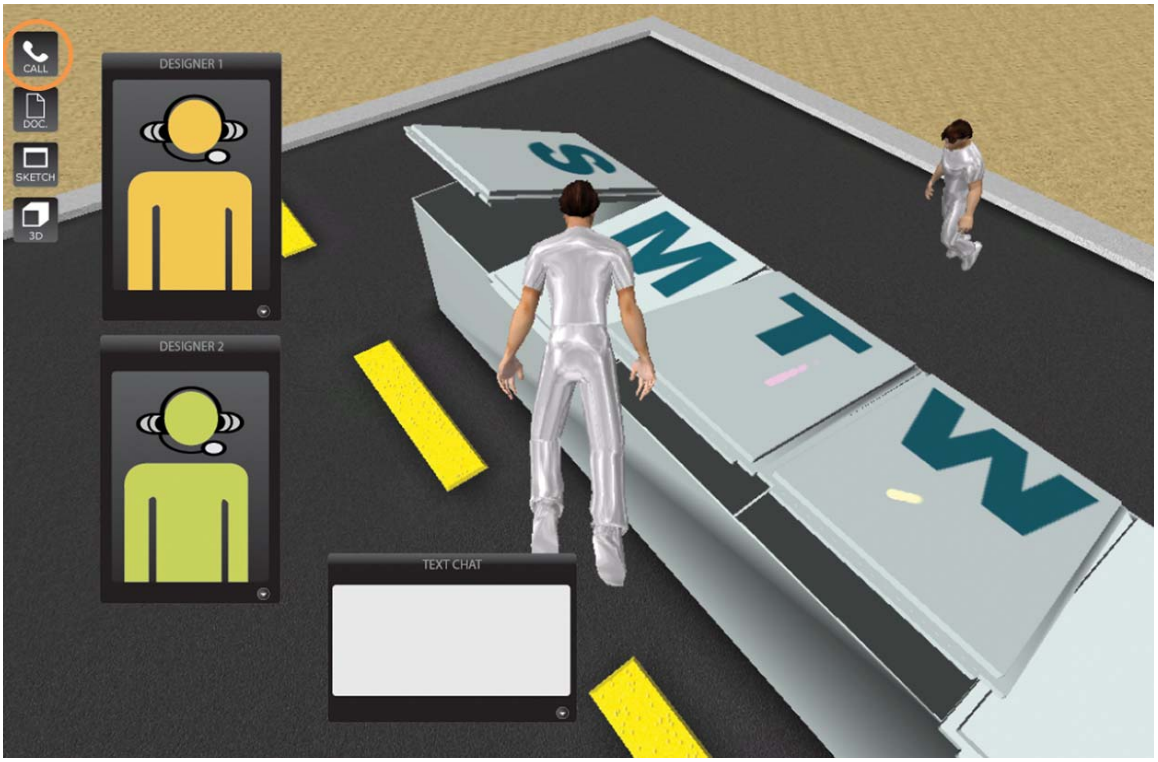


Figure 6.2 Visualized Recommendation for a Collaborative System

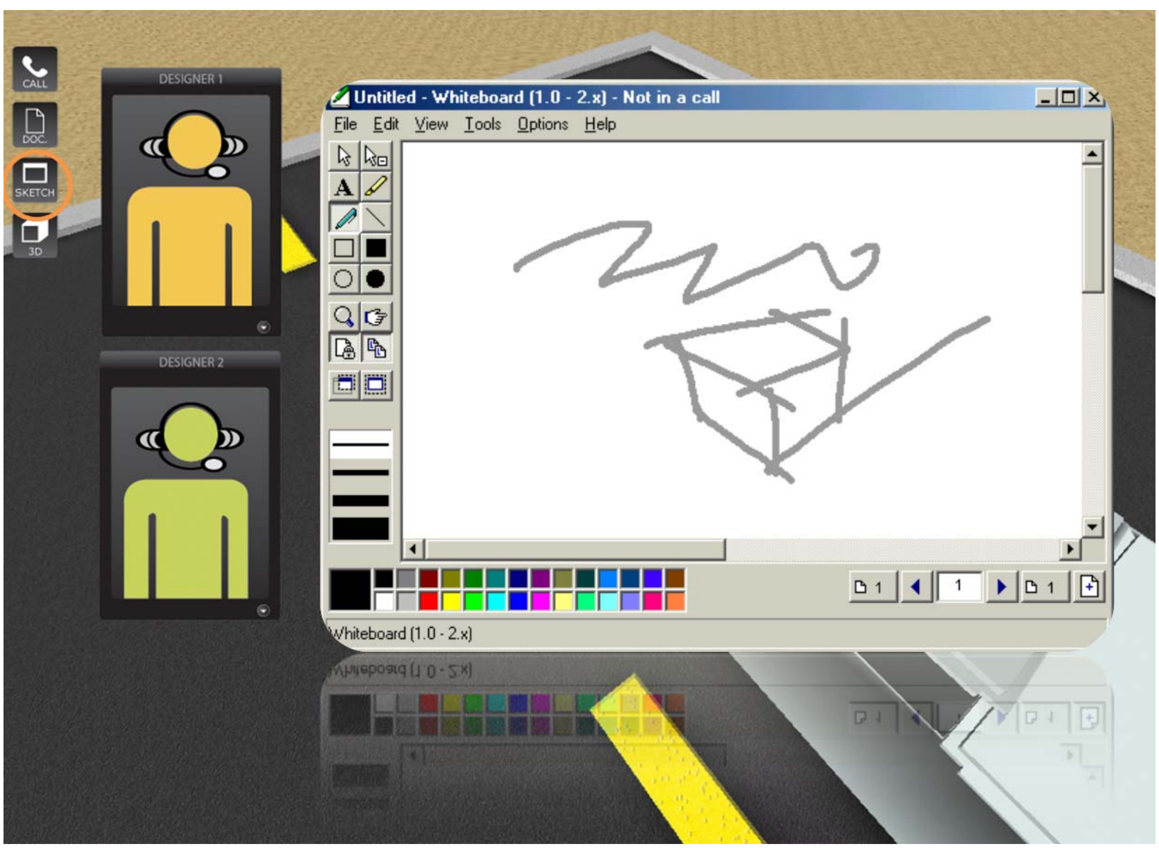


Figure 6.3 Sharing Whiteboard for a Sketch within a Virtual Environment

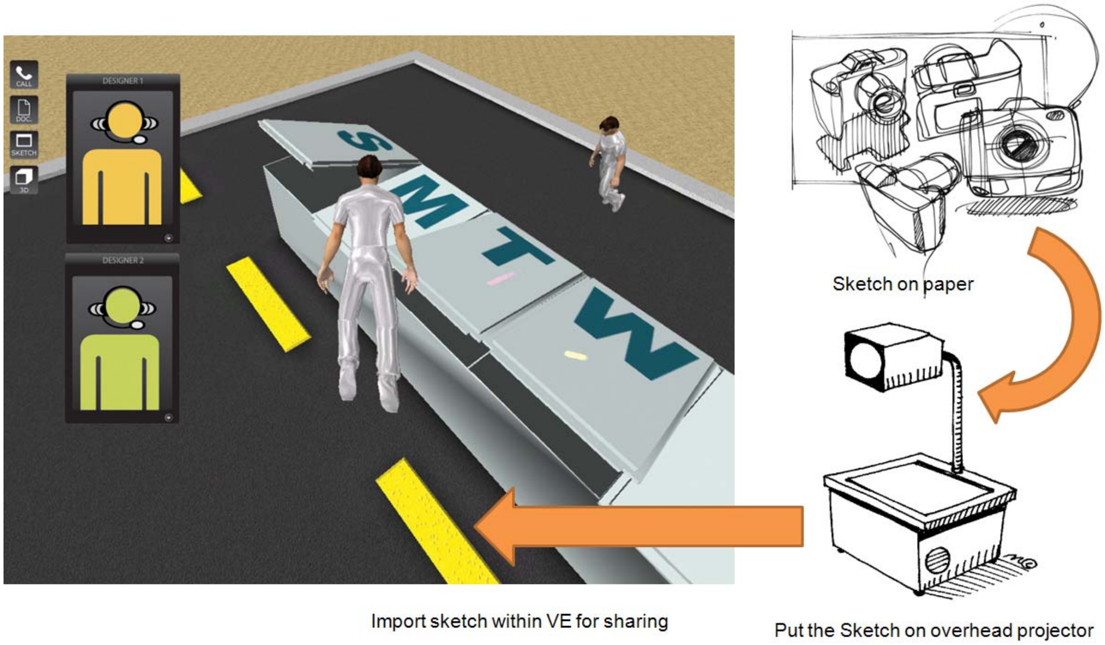


Figure 6.4 Sharing a Sketch on Paper Using a Overhead Projector Within a Virtual Environment

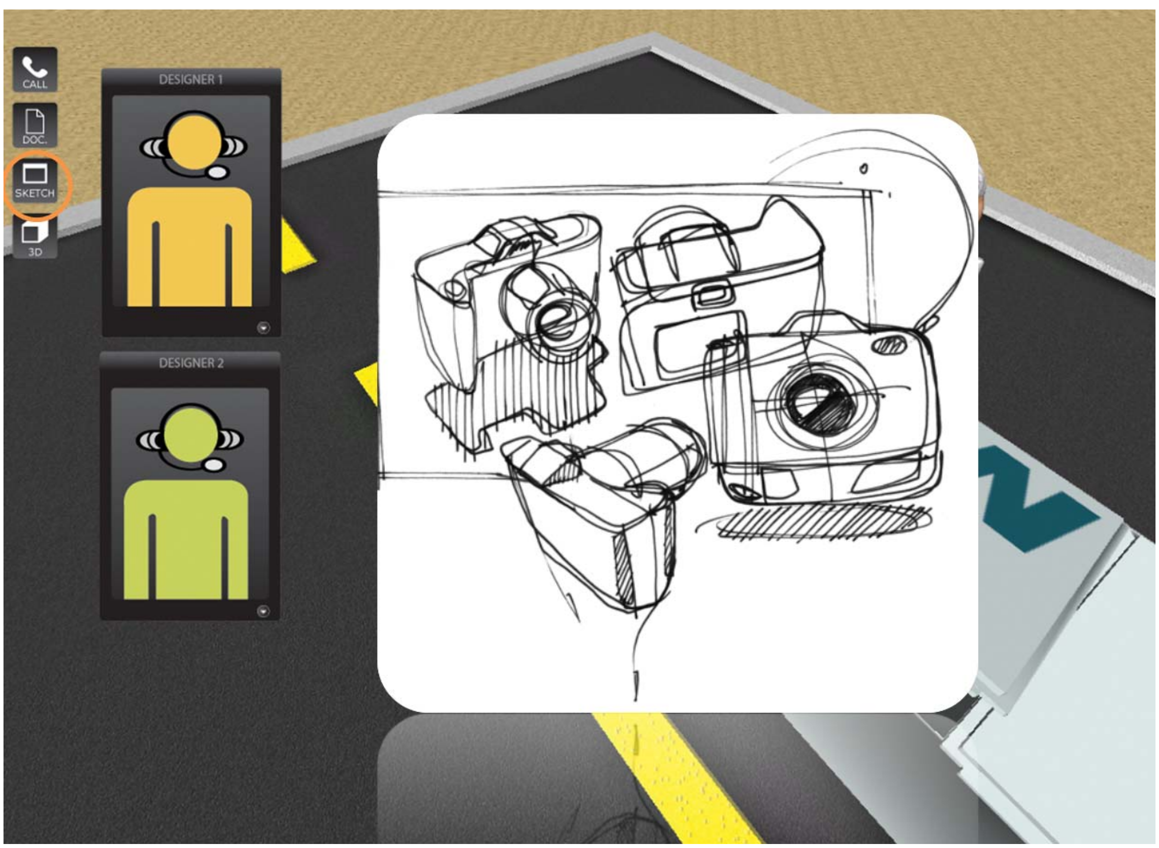


Figure 6.5 Sharking Sketch on Paper within a Virtual Environment

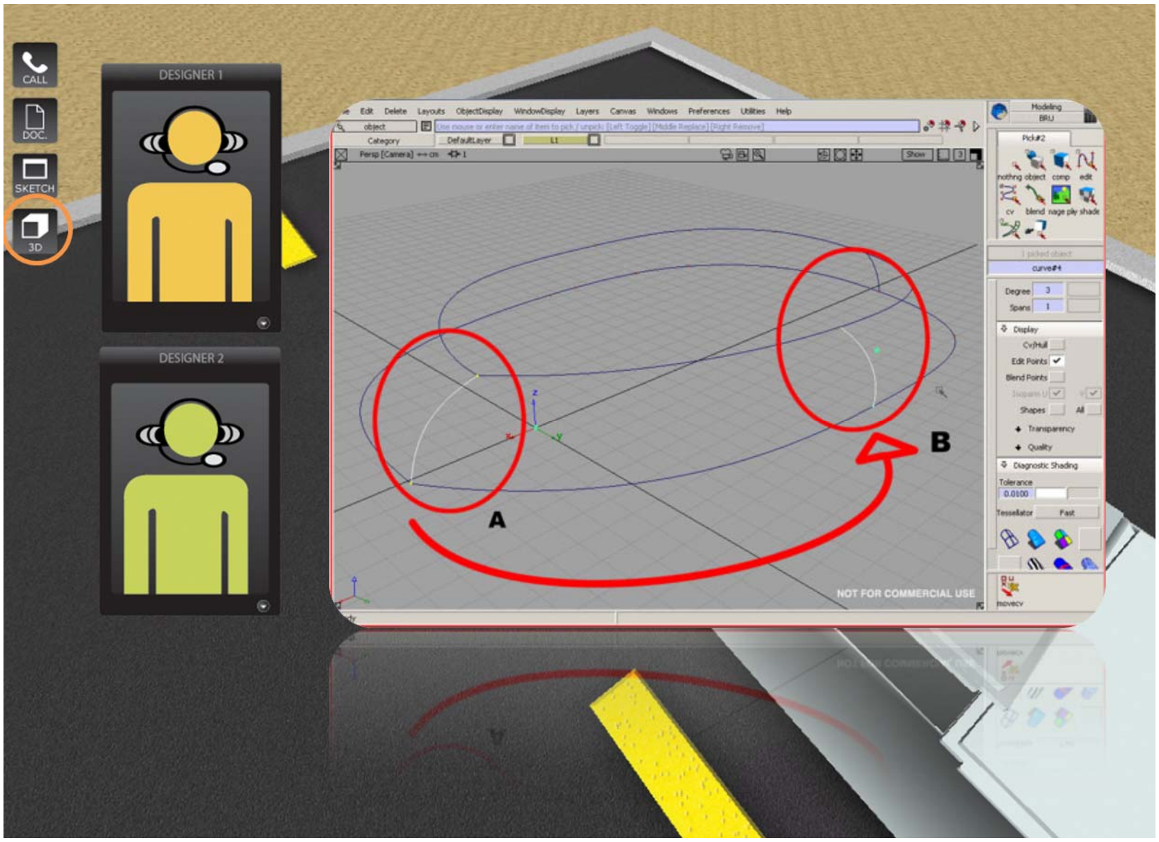


Figure 6.6 Sharing a 3D Program Within a Virtual Environment

Conclusion

Two studies presented in this thesis provided us useful information about how design teams work together and what types of technologies, such as CMC and CVE, help their collaboration in face-to-face and distributed settings. The results clearly show that the shared program and the whiteboard function from NetMeeting helped the design teams to share real time information, and increased the" together "working mode in the second study than in the first study. On average, teams worked together 29 minutes (48.3 % of the overall time) and 45 minutes (75% of the overall time) in the first and second experiment, respectively. While one designer was modeling in Solid Works, another designer was able to see the 3D object in a shared view at the same time to discuss some details of the design collaboratively.

We have an proposed outline of a collaborated system in the collaborative virtual environment. The CVE can be a tool with great potential if it provides better sharing capabilities, such as the capability to manipulate 3D modeling in CVE in real time. One interesting finding was that participants felt the distributed setting as a more engaging environment to work with teammates than the face-to-face setting. The found the use of shared tools increased the concentration level when they are distributed. This implies that a system for distributed design teams can be a more interactive, fun environment so that designers can enjoy communicating and collaborating together. Tangible interaction between design teams within a virtual environment will strongly enhance the collaboration for distributed design teams. To validate this, the research will need further work. A collaborative system based on the recommendation we provided can be built, and possibly inform the development of collaborative systems in the future.

APPENDIX A: INVITATION

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Dr. Jon Sanford, Tina Lee

- **Invitation**

Invitation

Dear Sir or Madam,

We are contacting you to ask for your help in a research study we are conducting.

The purpose of the study is to understand the way designers collaborate using existing Computer-Mediated Communication (CMC) technologies, such as email or instant messenger, and Collaborative Virtual Environments (CVEs), such as online graphics and CAD software in different settings: face-to-face and distributed. Ultimately, we would like to develop recommendations for a system that better supports design collaboration through sharing design information and interaction.

If you decide to be in this study, you will be asked to do two, one and a half -hour design sessions that will be conducted at the Center for Assistive Technology and Environmental Access (CATEA) at the Georgia Institute of Technology. For each design session you will be given a design problem you will need to solve with another participant. In the face-to-face setting you will be working together in the same place. In the distributed setting, you will be working together from different places.

To participate in the study we ask that you meet the following requirements:
1) You are at least 18 years old
2) You are a Junior, Senior or Graduate level student
3) You are familiar with Computer-mediated communication (CMC) technologies, such as email or instant messenger, and online graphics and CAD software, such as Adobe Illustrator or 3D-Max.
4) You have a basic understanding of the Unreal program through the class "Introduction to Online Visualization Environments".

Place: The Center for Assistive Technology and Environmental Access(CATEA)
490 Tenth Street, Atlanta, GA 30332-0156
Phone: 404-894-4960

If you have any questions about the study, you may contact the student investigator
Tina Lee at 404-831-1212 or tinalee@gatech.edu.

Thank you in advance for your help.

Best Regards,
Tina Lee

Georgia Institute of Technology | College of Architecture | Industrial Design Program

APPENDIX B: RESEARCH CONCENT FORM

Project Title: A system for distributed collaboration that supports sharing design information and interaction

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Research Consent Form**

Research Consent Form

You are being asked to be a volunteer in a research study.

Purpose
The purpose of this form is to tell you about the tasks you will be asked to do during two, one-hour design sessions and to inform you about your rights as a research volunteer. Feel free to ask any questions that you may have about the study, what you will be asked to do, and so on.

Thank you for your interest in participating in the study. Our work could not be completed without your help. The purpose of our research is to understand the way designers collaborate using existing Computer-mediated communication (CMC) technologies, such as email or instant messenger, and Collaborative Virtual Environments (CVEs), such as online graphics and CAD software in different settings: face-to-face and distributed. In the face-to-face setting you will be working together in the same place. In the distributed setting, you will be working together from different places. Ultimately, we would like to develop recommendations for a system for distributed collaboration that better supports design collaboration through sharing design information and interaction.

A total of 8 design students will participant in this project. You are being asked to participate in the study because you are 18 years and older and are a Junior, Senior or Graduate student who is familiar with CMC technologies, and CVEs.

Procedures

If you decide to be in this study, you will be asked to do two, one and a half -hour design session that will be conducted at the Center for Assistive Technology and Environmental Access at the Georgia Institute of Technology. At the beginning of each design workshop, you will first be given time to read through a design brief. You will then be given a design problem that you will need to solve with another participant, who will be your teammate. Each student will be randomly assigned to teams.

All teams will be asked to redesign two small products: an extension cord that can be pulled out of an electric socket with one hand, and a pill box for people who have memory loss. Groups will have access to both CMC and CVE technologies during the design process. To solve the design problem, you and your teammate will be asked to use some of the CMC technologies and Unreal Engine, a CVE technology, during the design process.

You will be given instructions on how to use Unreal Engine and time to practice using it before beginning the design problem. During a design session you will work with you teammate in two different settings: face-to-face and distributed. When you are working face-to-face with your teammate, you will be seated next to this other person and will be able to see him/her. When you are working in a distributed manner, you will be seated in different locations and will not be able to see or talk to each other except via CMC and CVE technologies. The researcher will inform participants at the beginning of each design workshop whether you will be in the face-to-face or the distributed setting.

Each design session will be videotaped so that we can review how you and your teammate work together on the design problem. At the end of each design workshop session, you will be asked to answer a few questions about your experience during the design process. The questions are designed to gather your experiences in the design workshop and your opinions about the design tools that you used. Once you are done with the first design workshop, we will ask you to schedule a time to come in for the second design workshop, which will be held a few days later. The second design workshop will have a similar format to the first, although we will also ask you to compare the experience between the two design tasks. Your final designs will be evaluated based on the criteria we give to you.

Consent Form approved by Georgia Tech IRB from January 20, 2009 to January 19, 2010.

Georgia Institute of Technology | College of Architecture | Industrial Design Program

Risks/Discomforts

The following risks/discomforts may occur as a result of your participation in this study:

- Participation in this study involves minimal risk or discomfort to you. Risks are minimal and do not exceed those of normal office work. Please tell us if you are having trouble with any task.

Benefits

You are not likely to benefit in any way from joining this study.

While you will not benefit directly by participating, we hope that we may learn something about design teams' collaboration way using different remote communication tools.

Compensation to You

There is no compensation to you for this study.

Confidentiality

The following procedures will be followed to keep your personal information confidential in this study: All written and video recorded data that are collected from you will be kept private to the extent allowed by law. To protect your privacy, your written and video records will be kept under codes which will be kept in a separate locked cabinet. The physical written and audio records will be kept in locked cabinets at CATEA at Georgia Tech and only study members will be allowed to look at them. The digital video files will be protected by password on hard drive at IMAGINE lab that can be only accessible authorized researchers. Participants' names and any other facts that might point to them will not appear when results of this study are presented or published.

We will ask to your permission to use the video gathered during the test for our reports and presentations. We will not present any video that will show your face (e.g., hands, back-of-the head, and screen shots only). We will not use your real name when the video is shown.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB will review study records. The Office of Human Research Protections may also look at study records.

Costs to You

There are no costs to you associated with participating in this study except some of your time.

In Case of Injury/Harm

If you are injured as a result of being in this study, please contact Dr. Neta Ezer at 908-670-6876. Neither the Georgia Institute of Technology nor the principle investigators have made provision for payment of costs associated with any injury resulting from participation in this study.

Participant Rights

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject:

- If you have any questions about the study, you may contact Student investigator Tina Lee at 404-831-1212.
- If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark, Georgia Institute of Technology at 404 894 6942.

By answering the survey questions you have agreed to be a participant in this study.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

____

Participant Name

____

Participant Signature **Date**

____

Investigator Name **Date**

____

Signature of Person Obtaining Consent **Date**

Consent Form approved by Georgia Tech IRB from January 20, 2009 to January 19, 2010.

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APPENDIX C: VIDEO RELEASE FORM

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Video Release Form**

Video Release Form
Georgia Institute of Technology

Project Title: A system for Distributed Collaboration That Supports Sharing Design Information and Interaction

Investigators: *Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee*

I give my permission to the project "A system for Distributed Collaboration That Supports Interaction and Sharing Design Information" to use the videotapes gathered during the experiment session of their studies in their research process and in their reports and presentations.

If you sign below, it means that you give us your permission to use the video for our project.

____
Participant Name

Participant Signature	**Date**
Investigator Name	**Date**
Signature of Person Obtaining Consent	**Date**

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APPENDIX D: INSTRUCTION FOR DESIGN TASK 1 (FIRST EXPERIMENT)

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Introduction for Design task 1 (First Experiment)**

Introduction

Task 1
A 60 year-old woman with mild memory loss has difficulty remembering to take her medication.

Redesign this pillbox (the design model of the pill box has been places in Unreal) or design for her based on the following criteria:

1. The pill box must be able to hold three types of pills:
   - Medication A is two pills taken twice a day (for a total of 4 pills each day). It must be taken first thing in the morning and right before bedtime.
   - Medication B is one pill taken three times a day with a meal.
   - Medication C is two pills taken once a day. It can be taken at anytime but must be taken at the same time each day.
2. At a minimum, the pill box must be hold medication for at least 1 days.
3. The pill box must be portable (e.g., fit into a purse).
4. The pill box must be easy to open for a person with mild arthritis in both hands.
5. The pill box must look visually appealing and not stigmatizing.

A 3D file with an existing pill box will be given to you. Work with your teammate to redesign this pill box based on the above criteria. **You are required to use the CVE (Unreal game engine) for this task**, however you will have a choice about which other tools you want to use. The following tools are available to you:

CMC	• Email • Skype • Instant messenger
CVE	• Unreal game engine • Unreal Editor
CAD	• Autodesk® 3ds Max® 2009 32-bit (3dsMax) • Solid Works • Adobe Illustrator CS3 • Adobe Photoshop CS3

Sharing system	• Net meeting
	  ◦ Share program
	  ◦ Chat
	  ◦ Whiteboard
	  ◦ Transfer files

Hardware	• Webcam and headset

You will have **only one (1) hour** to complete this redesign. Please use time appropriately so your design team could finish the design.
By the end of the hour your team should submit a 16"x16" posters (pdf format) of your final design outcome. This poster should include one perspective 3D design rendering and a concept description. A template and 3D file are available in the folder called **Resources** which is on your desktop. Place the poster in the same folder upon completion of the assignment.

If you have any questions at this time, please notify the experimenter.

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APPENDIX E: INSTRUCTION FOR DESIGN TASK 2 (FIRST EXPERIMENT)

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Introduction for Design task2 (First Experiment)**

Introduction

Task 2
A 50 year-old man who had lost his left hand in an accident has difficulty pulling out an electric socket from the device with only his right hand. He needs an extension cord to use his computer at work.
Redesign an extension cord for him based on the following criteria:

1. The extension cord must be able to be pulled out with one hand
2. The extension cord must designed be for an office environment (indoors)
3. The extension cord must be designed specifically for a electricity (need on/off button)
4. The extension cord must look visually appealing

A 3D file with an existing extension cord will be given to you. Work with your teammate to redesign this extension cord based on the above criteria. **You are required to use the CVE (Unreal game engine) for this task**, however you will have a choice about which other tools you want to use. The following tools are available to you:

CMC	• Email • Skype • Instant messenger
CVE	• Unreal game engine • Unreal Editor
CAD	• Autodesk® 3ds Max® 2009 32-bit (3dsMax) • Solid Works • Adobe Illustrator CS3 • Adobe Photoshop CS3

Sharing system	• Net meeting
	  • Share program
	  • Chat
	  • Whiteboard
	  • Transfer files

Hardware	• Webcam and headset

You will have **only one (1) hour** to complete this redesign. Please use time appropriately so your design team could finish the design.
By the end of the hour your team should submit a 16"x16" posters (pdf format) of your final design outcome. This poster should include one perspective 3D design rendering and a concept description. A template and 3D file are available in the folder called **Resources** which is on your desktop. Place the poster in the same folder upon completion of the assignment.

If you have any questions at this time, please notify the experimenter.

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APPENDIX F: INSTRUCTION FOR DESIGN TASK 1 (SECOND EXPERIMENT)

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Introduction for Design task 1 (Second Experiment)**

Introduction

Task 1
A 60 year-old woman with mild memory loss has difficulty remembering to take her medication.

Redesign this pillbox (the design model of the pill box has been places in Unreal) or design for her based on the following criteria:

6. The pill box must be able to hold three types of pills:
   - Medication A is two pills taken twice a day (for a total of 4 pills each day). It must be taken first thing in the morning and right before bedtime.
   - Medication B is one pill taken three times a day with a meal.
   - Medication C is two pills taken once a day. It can be taken at anytime but must be taken at the same time each day.
7. At a minimum, the pill box must be hold medication for at least 1 days.
8. The pill box must be portable (e.g., fit into a purse).
9. The pill box must be easy to open for a person with mild arthritis in both hands.
10. The pill box must look visually appealing and not stigmatizing.

A 3D file with an existing pill box will be given to you. Work with your teammate to redesign this pill box based on the above criteria. **You are required to use the CVE (Unreal game engine) for this task**, however you will have a choice about which other tools you want to use. The following tools are available to you:

CMC	• Email • Skype • Instant messenger
CVE	• Unreal game engine • Unreal Editor
CAD	• Autodesk® 3ds Max® 2009 32-bit (3dsMax) • Solid Works • Adobe Illustrator CS3 • Adobe Photoshop CS3

Sharing system	• Net meeting
	  • Share program
	  • Chat
	  • Whiteboard
	  • Transfer files

Hardware	• Webcam and headset

You will have **only one (1) hour** to complete this redesign. Please use time appropriately so your design team could finish the design.
By the end of the hour your team should submit a 16"x16" posters (pdf format) of your final design outcome. This poster should include one perspective 3D design rendering and a concept description. A template and 3D file are available in the folder called **Resources** which is on your desktop. Place the poster in the same folder upon completion of the assignment.

If you have any questions at this time, please notify the experimenter.

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APPENDIX G: INSTRUCTION FOR DESIGN TASK 2 (SECOND EXPERIMENT)

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Introduction for Design task 1 (Second Experiment)**

Introduction

Task 2
A 50 year-old man who had lost his left hand in an accident has difficulty pulling out an electric socket from the device with only his right hand. He needs an extension cord to use his computer at work.
Redesign an extension cord for him based on the following criteria:

1. The extension cord must be able to be pulled out with one hand
2. The extension cord must designed be for an office environment (indoors)
3. The extension cord must be designed specifically for a electricity (need on/off button)
4. The extension cord must look visually appealing

A 3D file with an existing extension cord will be given to you. Work with your teammate to redesign this extension cord based on the above criteria. **<u>You are required to use the CVE (Unreal game engine) for this task</u>**, however you will have a choice about which other tools you want to use. The following tools are available to you:

CMC	• Email • Skype • Instant messenger
CVE	• Unreal game engine • Unreal Editor
CAD	• Autodesk® 3ds Max® 2009 32-bit (3dsMax) • Solid Works • Adobe Illustrator CS3 • Adobe Photoshop CS3

Sharing system	• Net meeting
	  • Share program
	  • Chat
	  • Whiteboard
	  • Transfer files

Hardware	• Webcam and headset

You will have **only one (1) hour** to complete this redesign. Please use time appropriately so your design team could finish the design.
By the end of the hour your team should submit a 16"x16" posters (pdf format) of your final design outcome. This poster should include one perspective 3D design rendering and a concept description. A template and 3D file are available in the folder called **Resources** which is on your desktop. Place the poster in the same folder upon completion of the assignment.

If you have any questions at this time, please notify the experimenter.

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APPENDIX H: QUESTIONNARIES

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Questionnaires**

Date		**Time**	
SN		**Session**	Task 1 ☐ Task 2 ☐
		Setting	F2F ☐ Distributed ☐

1. Here is a list of Computer-mediated communication (CMC) technologies and Unreal, Collaborative Virtual Environments (CVEs) we provided for the collaborative design process. Please check the box that indicates whether you used the specific tool during the design session and explain why you used it or why you didn't use it.

CMC technologies and CVE	**Used**	**Did not Use**	**Why did you choose to use or not use this communication tool?**
Messenger	O	O	
Email	O	O	
Skype	O	O	
Unreal (CVE)	O	O	
Others (please specify)			

2. **Please rate based on the following criteria** on a scale 1 to 10, with 1 meaning poor and 10 meaning excellent.

	Poor									**Excellent**
	1	2	3	4	5	6	7	8	9	10
Overall										
how well you think **you** did during the design session, focusing on the quality of the final outcome	O	O	O	O	O	O	O	O	O	O
how well you think **<u>your teammate</u>** did during the design session, focusing on the quality of the final outcome	O	O	O	O	O	O	O	O	O	O
how well you think **<u>your team</u>** did during the design session, focusing to team effectiveness	O	O	O	O	O	O	O	O	O	O
Product (outcome)										
Quality	O	O	O	O	O	O	O	O	O	O
Level of productivity	O	O	O	O	O	O	O	O	O	O
Efficiency										
Process	O	O	O	O	O	O	O	O	O	O
Ability to collaborate with your teammate	O	O	O	O	O	O	O	O	O	O
Ability to communicate with your teammate	O	O	O	O	O	O	O	O	O	O
Tools										
Ability to use communication tools	O	O	O	O	O	O	O	O	O	O

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3. How effective did you feel the following Computer-mediated communication (CMC) technologies and Collaborative Virtual Environments (CVEs) were in terms of sharing design information?

Please rate based on the following criteria on a scale 1 to 10, with 1 meaning poor and 10 meaning excellent	Poor 1	2	3	4	5	6	7	8	9	Excellent 10	Didn't use it
CMC technologies											
Email	O	O	O	O	O	O	O	O	O	O	O
Messenger	O	O	O	O	O	O	O	O	O	O	O
Skype	O	O	O	O	O	O	O	O	O	O	O
CVE											
Unreal	O	O	O	O	O	O	O	O	O	O	O

4. Please share with us your opinion about the use of Unreal (CVEs) for the design process.

(e.g. it would be useful for design process because.....)

5. What do you feel would have helped you collaborate better with your teammate in the design session?

APPENDIX I: ADDITIONAL QUESTIONNARIES

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Questionnaires**

1. Have you used virtual shared 3D environments before? (not including this task)
Yes O No O
If yes, please specify what kinds of 3D environements have you used before? (e.g. Active Words, World of Kaneva, Second Life, Unreal, VRML)

2. In which setting, face-to-face or distributed, did you feel resulted in following criteria?

Criteria	Face-to-face	Distributed	Please explain why.
More successful design outcome	O	O	
More successful in sharing design information with your teammate	O	O	
More engaged to work with your teammate	O	O	
Prefer to work with your teammate	O	O	

3. Based on your experience in the two design sessions you completed, what are other key abilities you would like to see in a new system for distributed collaboration that facilitate sharing design information supporting interaction?

APPENDIX J: INTRODUCTION FOR UNREAL

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Instruction for Unreal**

1. Click Arch8803 on your desktop
2. Click ok
3. Hit **tilde** ~ and type open IP address (researcher will let you know the IP address)

How to control mouse and keyboard in unreal

Keyboard

Move Control

W : move forward
A : move left
D : move right
S : move back

F: to fly (hit F again to release)

B : behind view (hit B again to release)
T: to chat with others (type and hit enter)

`

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APPENDIX K: EVALUCATION CRITERIA FOR DESIGN TASK 1

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Grade sheet for design outcome (Task 1)**

Date		Time	
SN		Session	Task 1 ☐ Task 2 ☐
		Setting	F2F ☐ Distributed ☐
Grader		(ID faculty who are not involved this research)	

- Please rate the design based on the following criteria of the final outcome on a scale 1 to 10, with 1 as poor and 10 as excellent.

Please rate based on the following criteria	Poor 1	2	3	4	5	6	7	8	9	Excellent 10
1. The pill box able to hold three types of pills	O	O	O	O	O	O	O	O	O	O
2. The pill box can store medication for at least three days	O	O	O	O	O	O	O	O	O	O
3. The pill box is portable	O	O	O	O	O	O	O	O	O	O
4. The pill box is easy to open for a person with mild arthritis in both hands?	O	O	O	O	O	O	O	O	O	O
5. The pill box looks visually appealing and not stigmatizing?	O	O	O	O	O	O	O	O	O	O
6. How would you rate the overall pill box design? (i.e., Is this design successful based on clear articulation of a focused design intent and application of that intent in the design development?)	O	O	O	O	O	O	O	O	O	O

TOTAL GRADE	A+ 100	A 95	A- 90	B+ 89	B 85	B- 80	C+ 79	C 75	C- 70	D+ 69	D 65
	O	O	O	O	O	O	O	O	O	O	O
Comments											

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APPENDIX L: EVALUCATION CRITERIA FOR DESIGN TASK 2

Project Title: A system for distributed collaboration that supports interaction and sharing design information

Investigators
Dr. Neta Ezer, Dr. Ellen Do, Mr. Jon Sanford, Tina Lee

- **Grade sheet for design outcome (Task 2)**

Date		**Time**	
SN		**Session**	Task 1 ☐ Task 2 ☐
		Setting	F2F ☐ Distributed ☐
Grader		(ID faculty who are not involved this research)	

- Please rate the design based on the following criteria of the final outcome on a scale 1 to 10, with 1 as poor and 10 as excellent.

Please rate based on the following criteria	Poor 1	2	3	4	5	6	7	8	9	Excellent 10
1. The extension cord is able to be pulled out with one hand	○	○	○	○	○	○	○	○	○	○
2. The extension cord is designed be for an office environment	○	○	○	○	○	○	○	○	○	○
3. The extension ford is designed specifically for electricity (e.g. computer)	○	○	○	○	○	○	○	○	○	○
5. The extension cord looks visually appealing and not stigmatizing?	○	○	○	○	○	○	○	○	○	○
6. How would you rate the overall extension cord design? (i.e., Is this design successful based on clear articulation of a focused design intent and application of that intent in the design development?)	○	○	○	○	○	○	○	○	○	○

TOTAL GRADE	A+ 100	A 95	A- 90	B+ 89	B 85	B- 80	C+ 79	C 75	C- 70	D+ 69	D 65
	○	○	○	○	○	○	○	○	○	○	○

Comments

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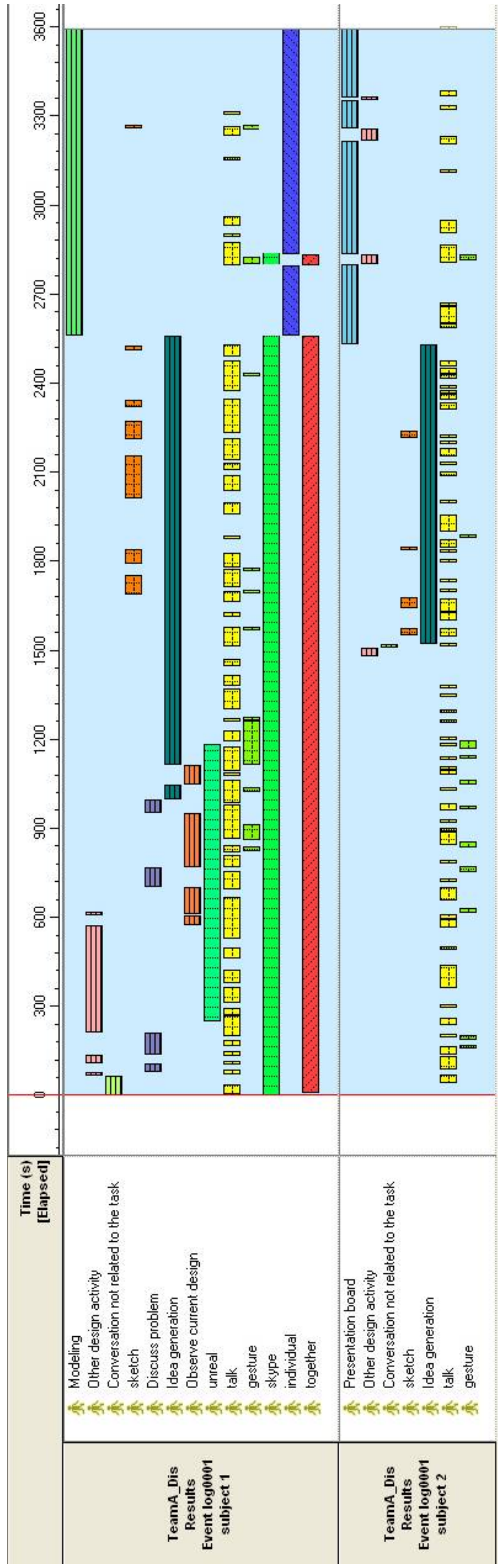
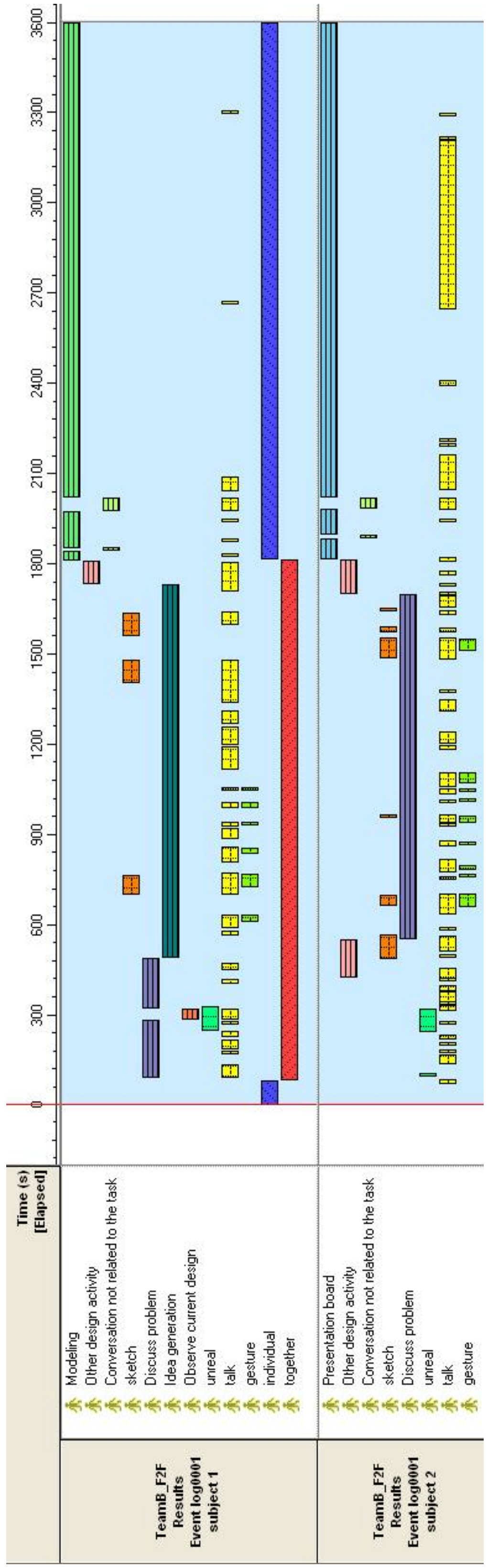
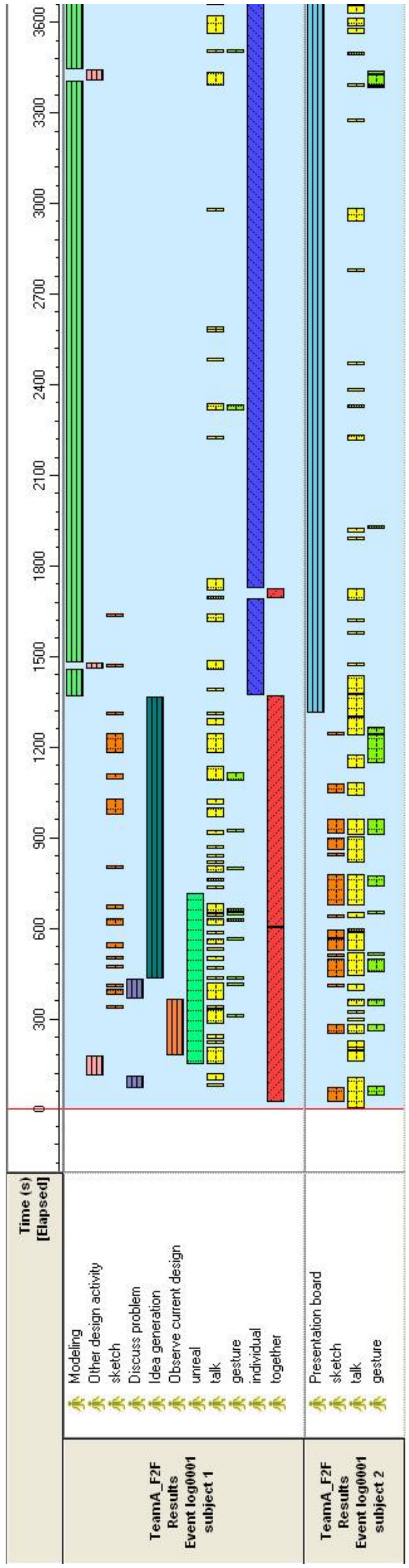
APPENDIX M: TEAM A (TASK 1: DISTRIBUTED)



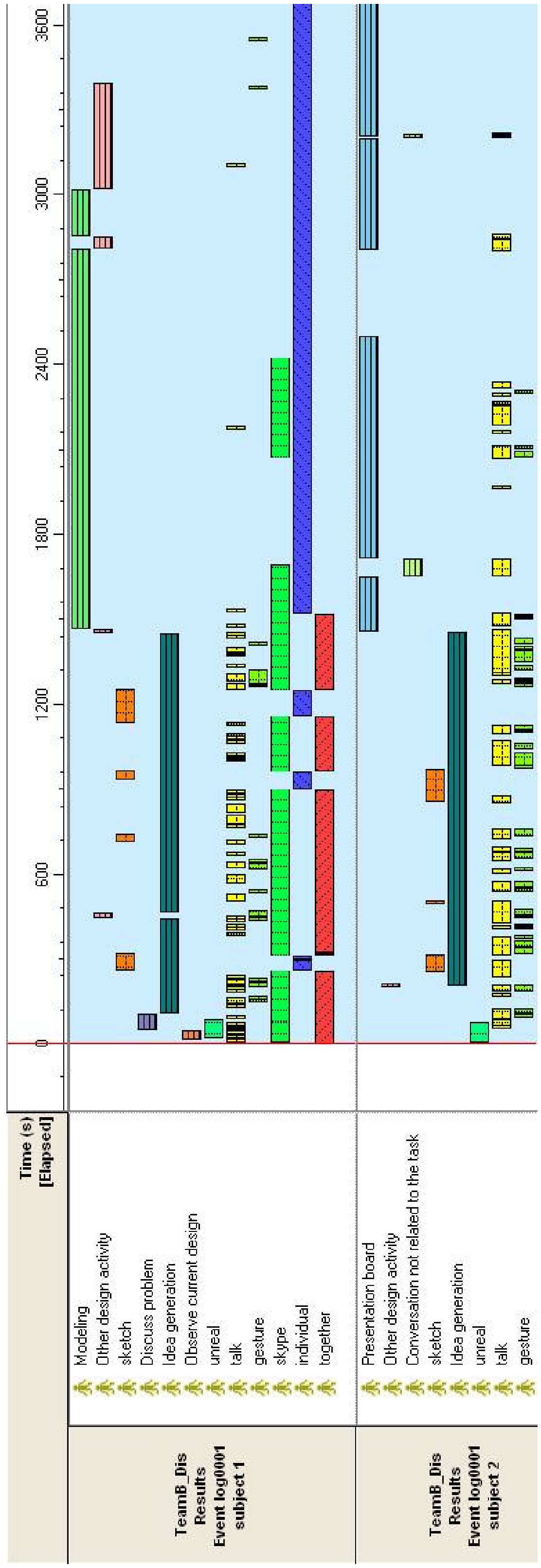
APPENDIX N: TEAM B (TASK 1: FACE-TO-FACE)



APPENDIX O: TEAM A (TASK 2: FACE-TO-FACE)

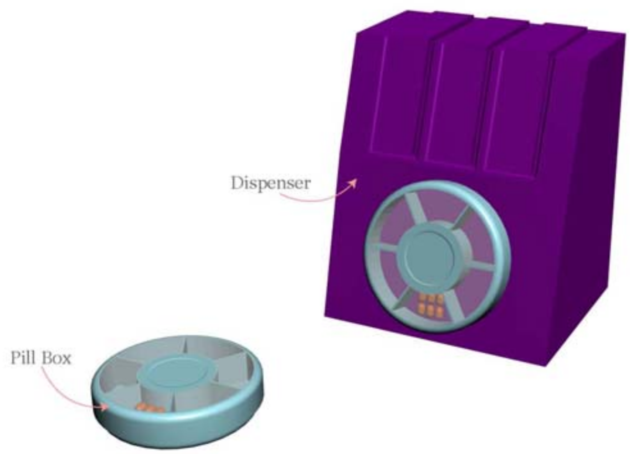


APPENDIX P: TEAM B (TASK 2:DISTRIBUTED)



APPENDIX Q: FINAL OUTCOME (TASK 1 : FACE-TO-FACE)

The user explains her problems by asking the following questions:
Which pill should i take?
How many of them should I take?
When should I take it?
How do I fill my box?
Can I take my pill box with me when I leave home?
Will my arthiritis come in the way of me using this device.



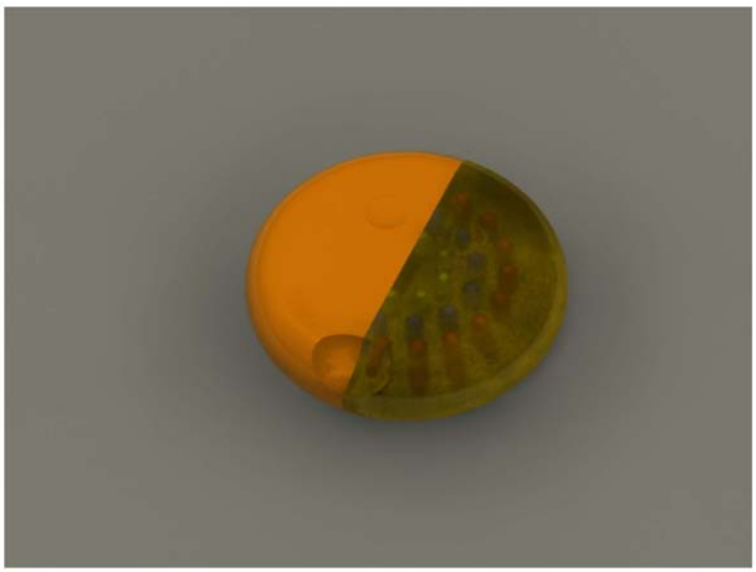
Concept Explanation
Ri-Cam pill system incorporates an easy to use device for reminding its user of taking the appropriate pill type and dosage.The center light acts as a beacon that reminds the user that it is time to take their medication. By pressing down on the light, the pills are released straight into the hands of the user.

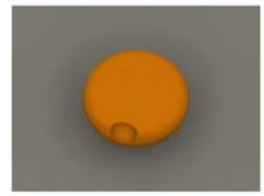
Programming the device is simple as well. There are two parts to this device, the pill box and the dispenser. The pill box is divided into times of day. The dispenser to the type of meds. The user matches the pills to the time of day they need to be taken and click the dispenser to release the meds into that time slot. Two clicks releases two meds

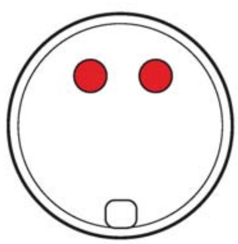
Ri-Cam pill system @ Collaboratvie Design Workshop 2009

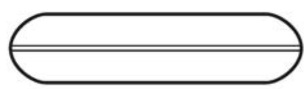
APPENDIX R: FINAL OUTCOME (TASK 1 : DISTRIBUTED)

Problem Statement: A pillbox is needed to store three types of pills taken at various intervals throughout the day. The pillbox needs allow pills to be accessible by an elderly woman over the age of 60.
The "OlnKey" is a radial pillbox design which can be loaded (by another automated device) with three types of pills. The device is small enough to attach to a cell phone. The OlnKey vibrates when the user needs to take the pills. The user then touches the two metallic divots on the device which actives the dispensing of the pills through the opening at the bottom.
Additionally, if after a certain amount of time, the user does not activate the dispenser, the OlnKey can call the user's cell phone. If the user still does not active the dispenser, the OlnKey can call the user's caregiver. The secondary device, the loader, is programmed by the caregiver. When the OlnKey is out of pills, the user attaches it to the dispenser. The loader device scans the OlnKey for pill usage, reloads the OlnKey, and records the user's pill usage, which is reviewed by the caregiver.









your project short name @ Collaboratvie Design Workshop 2009

APPENDIX S: FINAL OUTCOME (TASK 2 : FACE-TO-FACE)

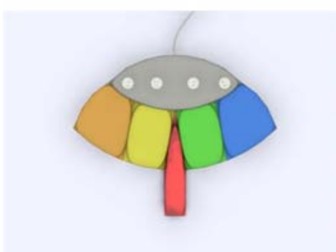
Problem Statement:
We are attempting to solve the problem of a 50-year old man who works in an office and constantly needs to switch hardware from an electrical outlet. His issue is that he has lost his hand in an accident and he needs an easy an efficient way to unplug his electrical devices from power strips and outlets with his one hand. He has no problem plugging in said devices, but since he only has one hand and no way to apply leverage, he needs a better solution other than the typical outlet. Hence, here is the Universal Foot Outlet, or U.F.O. It is designed to utilize the feet of the user to assist in this task.

The U.F.O. is the first of a series of products designed to help the elderly and disabled in their everday tasks of living.

The U.F.O uses patented "FootPedal" ® Technology to allow the users the option of pressing on a foot-lever to expel the plug that is placed in the outlet.

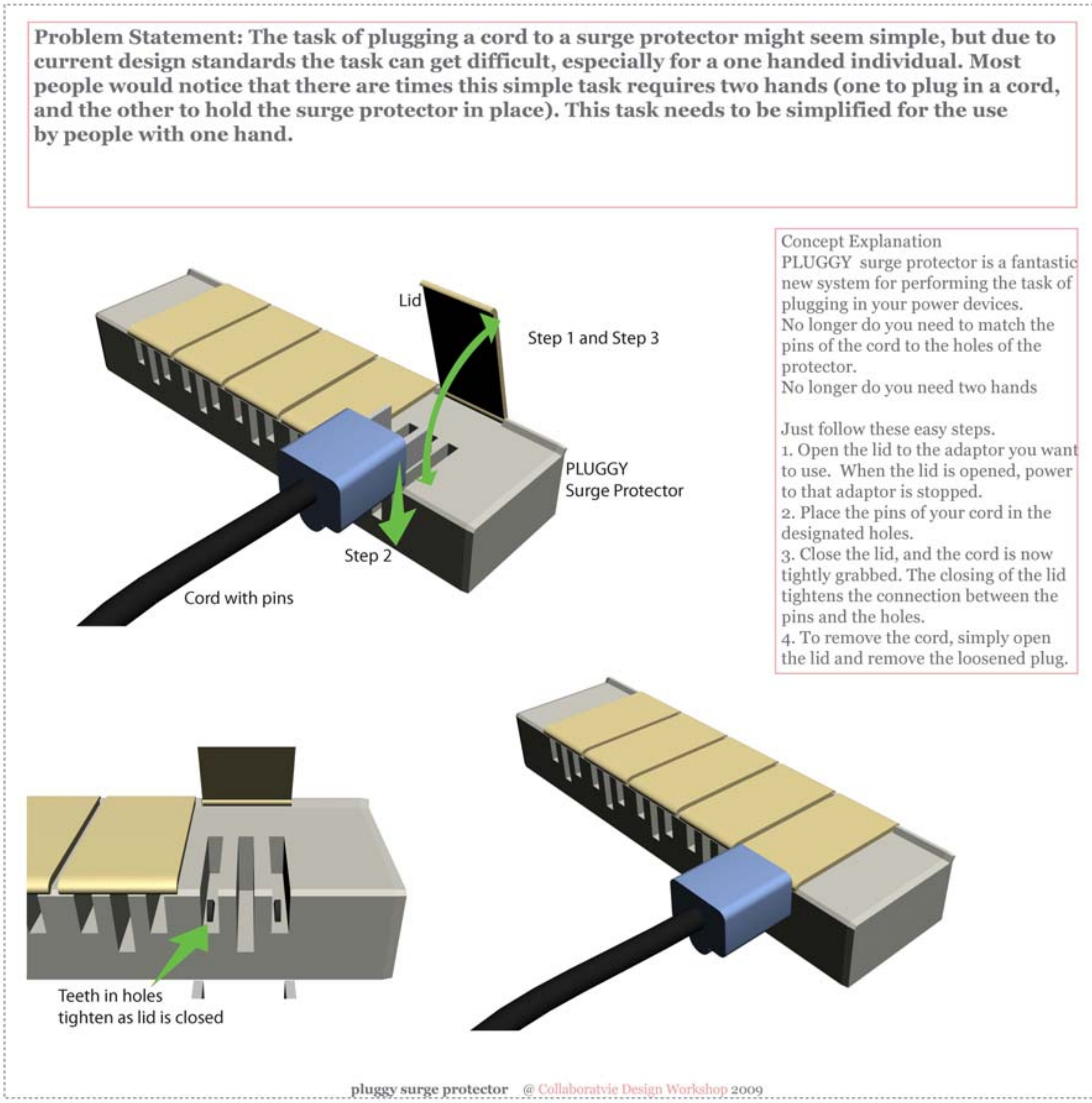
Since the outlets and FootPedals are color coded, you will not accidentally unplug a neccessary component. You can also use the optional Slip Cover™ system to sheath your component cables to further the color coding and ensure that you always unplug the correct component every time.

The product is visually appealing and saves space, and can be placed on the floor beneath the desk or table you are using for work, within reach of your feet. It is a convenience to all and doesn't neccessarily have to be used by the disabled exclusively. Buy one for your office and enjoy the benefits of a simple and effective system to plug all of your electronics in.

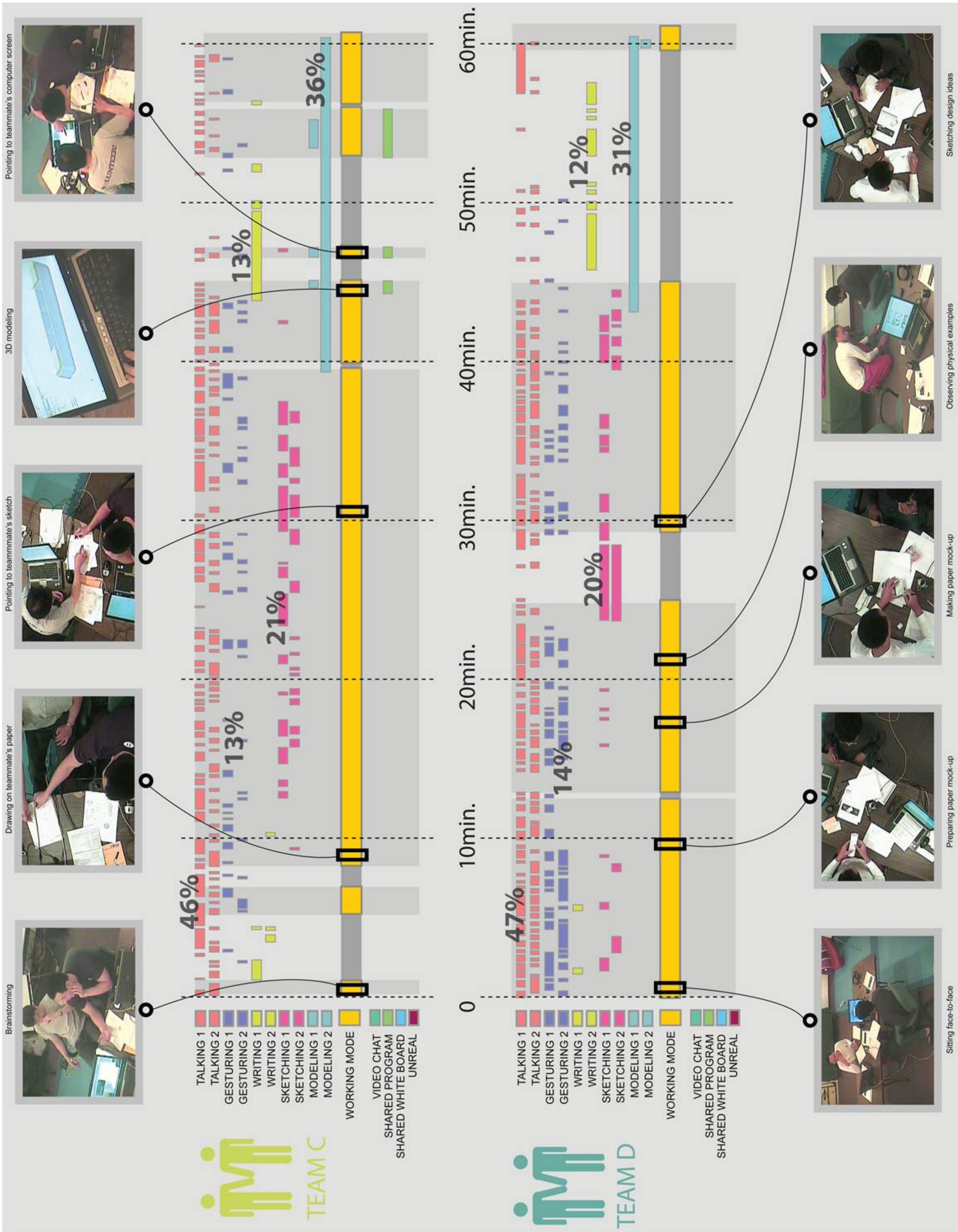


U.F.O @ Collaboratvie Design Workshop 2009

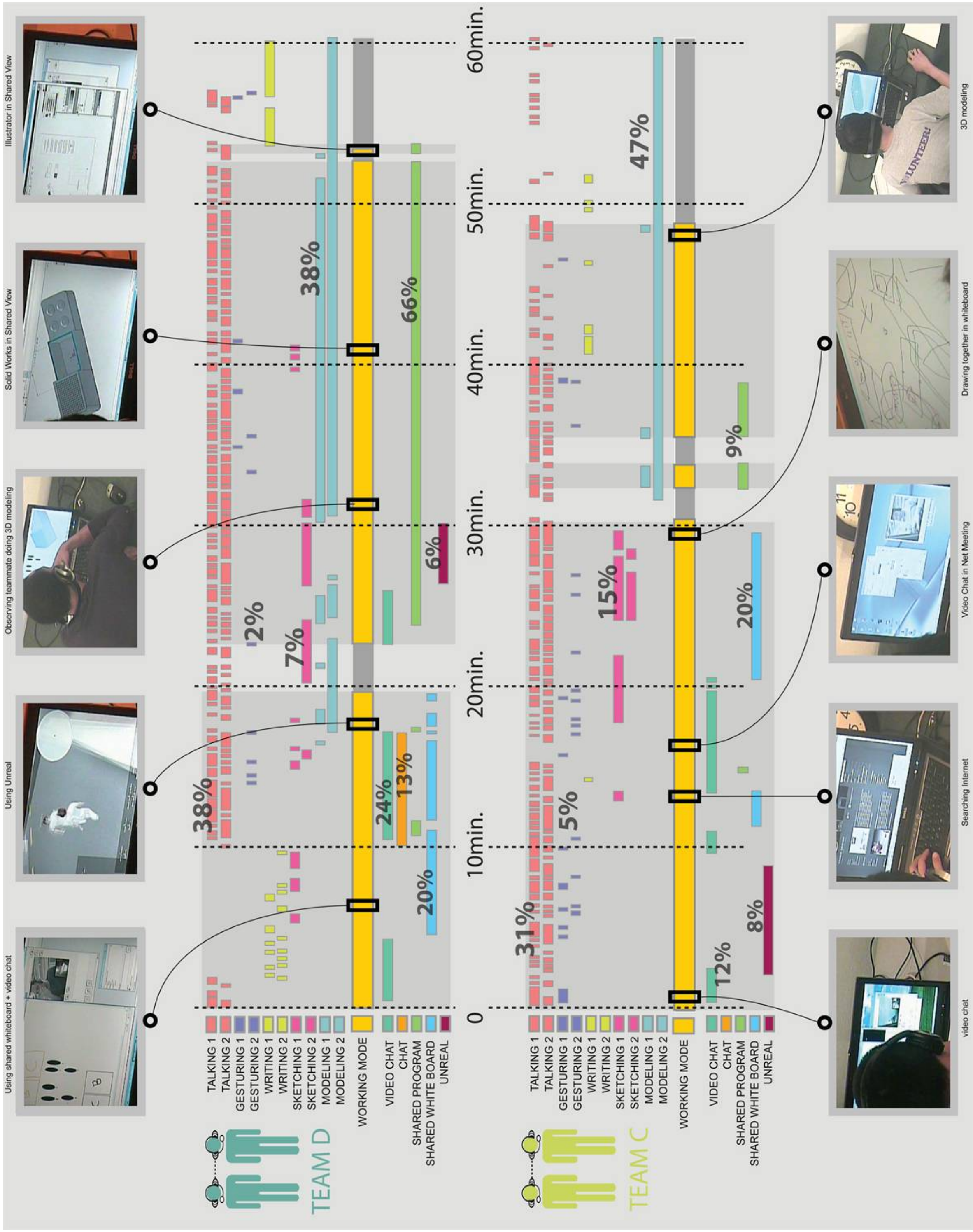
APPENDIX T: FINAL OUTCOME (TASK 2 : DISTRIBUTED)



APPENDIX U: COLLABORATIVE DESIGN PROCESS IN FACE-TO-FACE



APPENDIX V: COLLABORATIVE DESIGN PROCESS IN DISTRIBUTED



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